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TRANSACTIONS

OF THE

INSTITUTION OF CIVIL ENGINEERS

OF

IRELAND.

25TH AND 26TH SESSION, 1859-60-61.

VOL. VI.

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TRANSACTIONS

OF THE

Institution of Civil Engineers of Ireland.

TRANSACTIONS

OF THE

INSTITUTION OF CIVIL ENGINEERS

OF IRELAND.

[November 8, 1859.*]

ADDRESS OF M. B. MULLINS, Esq. A.M.,

PRESIDENT;

BEING AN HISTORICAL SKETCH OF ENGINEERING IN IRELAND.

The history of Civil Engineering in Ireland, as in every other country, dates from the commencement of commercial progress consequent on the yielding of the arts of war to those of peace; and as the former too long held precedence, we are not enabled to trace back our subject beyond a comparatively recent period, nor do the publications of the time furnish such memoirs as would enable us to form a precise judgment of the successive steps by which knowledge, properly so called, was obtained — facts formulated by the announcement of principles, and the profession raised to the rank of a scientific pursuit; but without drawing on our imaginations, those amongst us who have had an opportunity of ascertaining the earliest efforts of the Engineers belonging to the generation just passed away, are aware, that in the absence of an established school, and a dearth of professional books, a mathematical education, with a knowledge of surveying, were principally relied on, and with these qualifications, aided by natural constructive faculties of the mind,

* The reading of this Paper was continued on the Evenings of March 13, and May 22, 1860.

and that power of comparison called judgment, much was achieved through a laborious and costly experience; but in this retrospect, with which our time favourably contrasts, we cannot lose sight of the fact, that, although the science of construction then forming but one profession, is now divided into different branches, and great opportunities given for proficiency in each, we are still not exempt from the necessity of learning by actual practice, for which little or no opportunity in pupilage, at the time referred to, was afforded.

Seeing the great contrast in wealth and progressive improvement which England and Ireland—divided by a short and hitherto somewhat neglected sea passage—presents, it might, at first sight, be supposed, that the science of Civil Engineering had a very much earlier origin in the more advanced country, but it was not until after the termination of the war with France, by the peace of Paris in 1763, that a great impetus appears to have been given to the commerce and manufactures of England, and responsive to the demand then made for improved appliances, arose the genius of Smeaton and of Watt, by whom, with Brindley, Jessop, Chapman, Telford, Rennie, and others, was founded the school of Engineering in England, France having been previously the source to which recourse was obliged to be had for professional assistance, for we find that Westminster bridge, the first large structure of that description in England, was commenced in 1740, under Mr. Labelye, by whom Ramsgate harbour was also designed in 1744, and Brindley did not begin the Bridgewater canal until 1758, more than half a century after the completion of the great Languedoc canal, the mode of construction of whose locks was borrowed from the design of François Andreossi, a native of Italy—that land of classic recollections, where the seeds of an old civilisation, germinating with renewed cultivation, gave science, literature and art, to Europe, in the fifteenth and sixteenth centuries, and had no more dis-

tinguished masters than in the then united professions of architecture, military and civil engineering. And looking still farther back into the annals of the same gifted people, we find the various branches of our profession practically united in the best period of the Roman Empire.

Inland navigation appears, by the journals of the Irish House of Commons of the year 1697, to have been one of the principal objects contemplated by the legislature of that period, as a means of general improvement, but owing to their being no fund appointed for the purpose, no immediate steps were taken for its prosecution. It was not until a period commencing in the year 1755, when there was a surplus revenue in the treasury, that parliament became remarkable for its munificence in promoting public works, although, as the sequel will shew, considerable grants were made before that period. The expenditure under the control of the Navigation Board, which was established in the year 1730, having been found often profuse, and sometimes abortive, that body was dissolved, and a system was adopted of granting aid to private undertakers, proportioned to their subscriptions.

The depressed state of agriculture—the want of means of access to markets for the sale of farming produce, and the dependence of Dublin on importation for the supply of corn, flour, and coal, were the urgent motives for the remedial measures proposed, which, besides bounties on exportation, consisted of the improvement of the port of Dublin; the rendering of the Shannon navigable through its whole course, and connecting it, by means of a canal, with the sea at Dublin—as also the opening of communications between lough Neagh and the sea at Newry and Belfast, the former with the view to the transport of native coal from Drumglass collieries—these, with the formation of roads, were amongst the most important of the earlier works offering themselves for description.

The Ballast Office Corporation having been established in 1707, the first engineering efforts worthy of record may be said to have commenced about that period, having for their object the improvement of the harbour of Dublin; and as the subject is not devoid of either interest or instruction, I shall enter into some detail of the numerous plans proposed as well as of that executed, by way of contributing to the history of the ancient port of Dublin, believed to be known to Ptolemy, under the name of *Eblana Civitas;* and that this presumption does not rest on the usually slender grounds of our pretensions to importance of an ancient date, the fact is worth noticing, that Ptolemy described the city of Dublin as being on the eastern coast of Ireland, between the rivers Oboca and Bubinda, of the identity of which, with the Avoca and the Boyne, there can be no doubt; and Tacitus, in his life of Agricola, states, that owing to more frequent commercial intercourse, the ports of Ireland were better known than those of Great Britain.

The shallow bay about three miles in extent, at the head of which Dublin is situated, the entrance being between two large sand banks, called the North and South Bulls, presented great obstacles to the formation of a good harbour, and the rivers Liffey and Dodder spreading over a large space with but little depth at their confluence, not affording any effectual scouring power, offered unpromising prospects; for remedying those defects, however, with the view of deepening the water on the bar, the principle acted on was, to lead the waters of the two rivers and the ebbing and flowing tide in a straight line to the bay, by embanking them on each side as far down as Ringsend, and constructing a single line of works from Ringsend to the easternmost spit of the South Bull.

In 1711, in accordance with a plan suggested by Mr. Corneille (who was then employed at the harbour of Kinsale), and approved by the Surveyor-General, Captain Burgh, a

new straight channel was made from the city, (then terminating on the north side at Essex bridge,) as far as Ringsend. A bank of kishes, filled with stones, was, in the first instance, formed on the north side of the channel, to prevent the freshes of the river running over in that direction. In the same year the building of the south quay-wall was commenced, and in 1729 the North Wall was undertaken. Previous to the building of these walls the waters of the Liffey, Dodder, and Tolka rivers, with the currents of the tide, spread over a very large space, and, under the influence of floods and storms, threw up such shoals as made the navigation impracticable, rendering it necessary for vessels to discharge their cargoes in the bay near Dalkey.

In the year 1713, while the quay walls were building, Captain Perry proposed, for the improvement of the harbour, to construct a low wharf or pier of drift work from Irishtown to the outermost point of the South Bull, and to make a dam from Ringsend to the high land on the north side to pen the waters of the Liffey and Dodder above the high water of spring tides, with a stone sluice in the embankment to admit vessels into the basin. Before reaching the destined point great difficulty was encountered, and the work, a portion of which remained on the Sandymount strand in the year 1800, had been long previously abandoned.

Soon after the commencement of the building of the south quay-wall, a work of frames and piles, beginning at Ringsend, was carried on the south side into deep water, and was backed up by sand taken out of the channel by gabbards, but that description of material being liable to be carried away by the tide, a double stone wall, filled in with gravel, was substituted in 1748, and continued for a length of 7,938 feet, to nearly where the Pigeon House now stands, as recommended by the Ballast Board, on the ground that the basin, within the bar, being thereby made larger, and enabled to contain more

water, there would be increased scope for the flux and reflux of the tides to deepen the channel, which they feared had been prejudiced by shutting the water out of the harbour, by the taking in of Sir John Rogerson's ground, and the construction of the North Wall.

From the site of the Pigeon-house to the eastern spit of the South Bull, the frames and piles were carried to a distance of 9,816 feet, but the maintenance of them having proved very expensive, and not affording sufficient shelter to the channel, it was resolved to substitute a wall in their stead also. This was begun at the eastern extremity in 1761, by the construction of the lighthouse, and from thence the work was carried to the site of the Pigeon-house, or, as it was then called, the Block-house.

The determination to commence at the eastern extremity was come to with the view of protecting, by the abutment, the floating ship-light erected in 1735, which was subject to be displaced in tempestuous weather, when it was most required.

The wall or pier commenced under the direction of Mr. John Smith, as Engineer, is composed of two parallel walls built in header and stretcher courses, with large blocks of hewn granite without cement, up to the level of low water, the intermediate space being filled with promiscuous rubble; over this a course of masonry was laid in tarras cement, and the whole finished in courses of granite of large dimensions, the coping having from 6 to 7 feet insertion. On the top course of the portion of the pier extending into deep water where the force of the sea was most apprehended, a framework of timber was bolted down, but this having been found a very inadequate protection in south-easterly gales, the raising of the wall several feet in height towards the extremity, proved to be the only effectual remedy.

The pier is 32 feet in breadth at bottom, battering to 28 feet at top, the height is nearly 7 feet above the high-water

line, and the whole is 17,754 feet, or nearly 3¼ miles in length, and must be considered one of the most remarkable, and, taken with what was subsequently achieved in furtherance of the object in view, one of the most successful efforts on record in overcoming a great engineeing difficulty.

The lighthouse, is circular, with a considerable batter, of the same material as the pier, and was designed and superintended by Mr. John Smith, who was occupied until 1768 in its construction. The abutment, as it was called, or foundation, is a hexagon 36 feet in diameter, consisting of large blocks laid in caissons, the bottom being first carefully prepared to receive them. A mass of promiscuous rubble was then thrown in all round and a buttress of solid masonry, 25 feet wide at its base, was carried up to the level of low water. The shaft consists of three stories separated by groined arches. The lantern, in the original structure, was accessible by a stone staircase winding round the exterior and terminating in an iron gallery at the level of the upper storey. The light is 68 feet above high-water, and is visible about 12 miles. At half-tide, when there was sufficient water for ships to come into the harbour, a flag was hoisted at the top of the lighthouse, and at night a small light was shewn, under the principal one, for a like indication.

The permanency of this structure, which has withstood the force of south-easterly gales, in a very exposed situation, and in deep water, testifies amply to the skilful mode of its construction.

After the building of the lighthouse, the construction of the South Wall made such tedious progress, that the piles became decayed, the stone filling of the interspaces was carried away by the sea, and the sand having become greatly raised on the South Bull in consequence of the piling, was filling up the channel; under these circumstances the merchants petitioned to amend the laws relating to the

conservation of the port, and an act was, in consequence, passed in 1786, transferring all powers concerning the Liffey and the harbour, together with the pilotage, to a new corporation for preserving and improving the port of Dublin. At this time there was built of the South Wall, according to Whitlaw, from the lighthouse towards the Pigeon-house, 1,522 feet, the remainder was completed in 1796, and a basin was constructed, 900 by 450 feet, near the fort, for the safety of the packets exposed to the swell in the channel in easterly winds. There being no fortress in Dublin, in which the public archives could be kept, the Pigeon-house fort was destined for that purpose, and with the view of supplying the garrison with water within its precincts, a very large sum was laid out, under the direction of Sir Hyde Page, in sinking an artesian well, but it had to be abandoned, on account of the admixture with salt water.

A survey of the bay and harbour, made by Collins, in 1693, shows that the bar extended, at a uniform level, across the entrance, without any channel through it. There were neither piles nor wall at that time, and Ringsend was represented like a fortress.

Soundings were taken in 1725, by Captains Burgh and Perry, who stated in their report, dated 17th September of that year, that they found the channel generally deeper, and several perches wider, than it was at the commencement of the works. These soundings were laid down on a map of the harbour, published by Mr. Gabriel Stokes, and showed that the depths differed little from what they were in 1711, when soundings were made by order of the Ballast Board, namely, 19 to 21 feet water on the bar, and 19 feet at the buoy of the bar at high-water of spring tides, which rise from 12 to 14 feet. In 1751, M'Kenzie made a survey amounting to little more than an outline of the bay. On it, the depths in the bar-channel, at low water of springs, are marked as 8 feet,

and in the reach from the Pigeon-house to the quays, 2 feet.

According to a report and survey of the Harbour, made by Captain Bligh, in the year 1801, by order of the Directors-General of Inland Navigation, it appeared that the bar was two miles in length, and half a mile in width, connected by a broad base with the North Bull, and tapering towards the south, where its nearest part was about 600 yards distant from the lighthouse. It consisted of small hard sand to the depth of 16 feet, the limit of the soundings by Captain Corneille, and was perfectly free from any admixture of the city sewage, which was then deposited between the quay-walls and on the Clontarf shore. There were from 5 to 5½ feet of water on the shoalest part of the bar, at low-water of ordinary spring tides, and from 19 to 19½ feet at the top of the tide. It appeared also, that the south end of the bar had been to some extent worn away. The Rev. Bernard MacMahon, whose almanac was the received authority of the day, made the greatest height of water on the bar to be 20 feet 10 inches.

Such was the limited extent of the deepening produced by the building of the South Wall, at a cost of £200,000, but it enabled the channel into the harbour to be made of a more uniform depth—afforded to vessels the desired protection in south-easterly winds—prevented the influx of sand with the tide from the southward, and directed towards the bar the ebb tide, much of which had theretofore run over the South Bull. However, these results not having been found sufficiently satisfactory, recourse was had to various professional advice, in order to devise means of creating such a scour as would further deepen or altogether remove the bar.

Mr. William Chapman, who had been early consulted on the subject by the authorities, published an elaborate report in the year 1786, (when the South Wall had been partly constructed) on the effect of the Dodder on the harbour of

Dublin, of which he made a survey, and recommended the projection of a pier from the Clontarf shore towards the lighthouse, and thence, with a bend westward, to a proper distance from the North Wall, so as to confine all the tidal water covering the vast space, and to make it pass down the pool by the channel, instead of being permitted to flow inwards, and outwards over the North Bull.

Captain Bligh in his report of the year 1800, already referred to, proposed to confine the river by a wall on the north side, extending nearly as far as the lighthouse, with the view, as stated, of causing the water to rise higher, in order that in its reflux it might produce a scour.

The Ballast Board having been aware that, in easterly and southerly gales, a heavy swell running along the face of the great wall created considerable agitation and danger to vessels lying within as well as difficulty in passing the bar, suggested, in the year 1801, to the Directors-General of Inland Navigation, as recommended by Chapman, the construction of a pier or other work which should commence at or near the spot where the buoy on the spit of the bar, nearly opposite the lighthouse, was then placed, this pier or wall to commence with a lighthouse nearly similar to that on the south side, and to be continued to such part of the northern shore as might appear most advisable, both with respect to the quantity of water to be reserved within the harbour, the direction to be given to that water in its flood and ebb, and also with respect to the line where foundations might be most practicable and safe. The advantages contemplated were of a like character to those already attained on the south side, namely, the sheltering of the harbour from all winds to the northward of east, preventing the influx of sand with the tide from the eastward, and directing the ebb altogether against the bar and through the harbour mouth. It was also suggested, that a question might arise in the progress of the work whether it

would be desirable to run the wall home to the north shore or to stop some distance short of it.

A full appreciation of the value of the water flowing into the harbour having been arrived at, and it having been observed that the North Bull had greatly increased, both in extent and height, since the completion of the works on the south side, and that the tide took different directions on either side of it, one branch running in by Sutton, the other by the lighthouse, and that as the tide flowed, so it ebbed through these two channels, consequently that the proposed wall, if continued to the shore, would cut off a considerable part of the gut eastward of Clontarf, and that a valuable body of water would thus be excluded from the harbour, it was therefore submitted by the Ballast Board for the consideration of the Directors-General, whether benefit might not be derived by stopping the proposed wall at some distance from the Clontarf shore.

Captain Corneille having been ordered, in the year 1801, by the Directors-General, to make a special examination of the harbour with reference to the proposition of the Ballast Board, reported in favour of the wall, and recommended that it should be carried from the point of land east of Clontarf Sheds in a right line to the spit buoy, leaving an open space of half an English mile between its termination and the lighthouse, by which means the whole body of water required to fill the harbour should come through the opening, and the tide would be prevented flowing over the North Bull into the harbour.

Sir Thomas Hyde Page was in favour of a second wall or bank, to commence from the North Lots, as suggested by the Directors-General, in order to confine the course of the water to one channel, and thereby to cause increased depth. This wall, to enclose the Liffey and part of the North Bull, was proposed to be 7,000 yards in length, and to be constructed at a cost of £168,000. A further project of the same Engineer was to raise part of the bar about half a mile in length above

high water, by means of facines and stones, so as to form an island, with a view of confining the current to certain lines of direction, and causing deeper water. The estimate for the formation of the island was £72,000.

Mr. Rennie having been called on in the year 1802, to give his opinion on the whole question, zealously enquired into by the Directors-General. He commenced his report by stating that the improvement of Dublin harbour was one of the most difficult subjects which had perhaps ever come under the consideration of the Civil Engineer, and therefore required to be treated with great caution and judgment.

He observed, that from the limited extent of deepening the water on the bar, produced by the extensive works already executed, he had not any very sanguine hopes of much good being accomplished by any works to be added at a moderate expense, that the scouring away of bars was, at best, but an uncertain operation, and could only be done by bringing an additional quantity of water to act on them, or by confining the action of whatever water there is to a narrower channel. The plan, therefore, that occurred to him as best suited to this purpose, was as follows:—

First—To build a pier from near the spit buoy, off the North Bull, to the Clontarf shore, about half a mile east of the Sheds, leaving an opening of about 550 yards between its head and the south wall or pier.

Secondly—To embank the South Bull, so as to enclose about 1,300 English acres, and to make a large opening in the South Wall, near Ringsend (arching it over for the road), to admit the tide into this space as a reservoir.

Thirdly—To make low jetties on the flat shore, from the channel towards the Clontarf shore, to direct the water, on the south as well as on the north side of the ship channel, in one course, both in the first quarter of flood and last quarter of ebb, when its scouring power would be the greatest.

The new proposed north pier or wall to the Clontarf shore, enclosing about 2,500 statute acres, over which the tide would flow to the average depth of from 7 to 8 feet in springs, and the South Bull enclosure, containing about 1,300 acres, with an average depth of from 5 to 6 feet in spring tides, would cause about 36,000,000 tons of water to ebb and flow through the mouth of the harbour in spring tides, and would pretty nearly double its scouring power.

Great as this scouring power might appear, Rennie was still doubtful whether it would produce much effect in deepening the bar, for, as the water had so much room to spread after passing the pier heads, the distance of the nearest part of the bar from the lighthouse being nearly 600 yards, and its average breadth about half a mile, with from 5 to 7 feet of water on it at low water, he was of opinion that with all the assistance possible to be given to it by ploughing or dredging the bar (composed of small hard sand), not more than a foot of additional depth of water would be got by an outlay estimated at £252,000. That the principal advantage would be shelter, and that this would be gaining little at a great expense.

Rennie came to the conclusion that if any considerable depth were to be obtained on the bar, it should be by extending the present pier about 800 yards, and also building another from the south head of the proposed pier, from the North Lotts, for about 1,100 yards in length. These piers placed, as shown on the plan, and splayed at the mouth, would confine the water ebbing and flowing through the entrance into the harbour, and that from the reservoir of the South Bull, so as to act with much more effect on the bar than by being left at liberty to spread after it had passed the lighthouse; and if the bar were ballasted and dredged while the works were under execution, he had no doubt that an additional depth of water of about 3 feet might be obtained.

The direction given to the piers would admit of vessels entering the harbour easily, and there would be quiet water within even in storms from the south-east.

The expense of these additions was estimated at £403,488, making, with the works previously described, a total of £655,872 for the further improvement of the harbour, by which it was expected that 3 feet additional depth would be got over the bar; that is to say, there would be from 8 to 9 feet at low water of spring tides, instead of from 5 to 6, as there was then.

It must be admitted that no narrow spirit of economy seemed to stand in the way of making adequate plans of works in the times referred to.

In 1819, after much discussion, the bold measure of the north pier or embankment, recommended by Chapman, having been determined on, its position from the Clontarf shore to the spit buoy, was planned by Mr. Giles and Mr. Halpin, who, in their joint report, of May, 1819, refer to the propriety of its construction "in the probable event of the South Wall being extended from the lighthouse towards the bar, and the wall or embankment on the north side being also carried to the bar." The wall was formed by throwing in rough granite blocks promiscuously.

In the autumn of 1822, Telford and Whidbey were consulted by the Ballast Board as to the state of the works, the effect produced by the pier, and what ulterior measures they would recommend. These Engineers reported that they found 5,500 feet in length of the wall built to its full height, 1,500 feet to the level of high water of neaps, and 500 feet to the level of half-flood. The effects they stated to be very evident, for the sand-banks in the interior having been deprived of their usual supply from the great north bank, were already lowered more than three feet on an average, while the part of the bar immediately opposite to the harbour mouth had been

lowered from 6 feet 6 inches to 8 and even 9 feet; and the western part of the bar, adjacent to the old channel, was 7 and 7 feet 6 inches, so that already a direct entrance was of sufficient depth for most of the vessels frequenting the port of Dublin. The conclusion come to was, that an extension of the wall, 500 feet in length, should be carried forward as recommended by Mr. Halpin, the effect of it to be watched with caution and not to be raised in the first instance above the level of half-tides. The whole was completed in 1823, at a level of 7 feet above high-water of spring tides.

When this well-considered work was finished, a systematic course of dredging was commenced in the upper portion of the river, and was attended with such satisfactory results that vessels of a large class, instead of lightening their cargoes twice, as formerly, at Poolbeg, and nearer the bar, can come without interruption to the quays in Dublin at high water.

Giles's survey, made in 1818 and 1819, by order of the Ballast Board, having been conducted with much care, affords the means of comparison with previous and subsequent soundings. On his map, as in Bligh's, the ridge of the bar is shewn crossing the entrance to the Liffey, having on it from 5 to 6 feet at low water of spring tides, and in the southern channel, then the principal one, narrow and winding as it was, the depth was only 8 feet. At the Ford the greatest depth was 7 feet, and that merely in a small passage next to the northern bank, and, in the long reach from the Pigeon-house to the quays, the general depths varied from 2 to 4 feet.

The admiralty chart, made by Captain Frazer, R. N., in 1838, compared with the surveys of Bligh and Giles, shows that a great improvement had been effected. In the east or direct channel of the bar, the least depth marked is 11 feet at low water of spring tides, giving a depth of 25 feet at high water. The depth in that channel was, in 1819, only 6 feet 6 inches, and in 1800 only 5 feet at low water, whereas it is

now the main channel with a considerably increased breadth as well as depth, and affords a direct passage seaward, through what had formerly been part of the curved ridge of the bar. From the bar to the lighthouse, depths of from 12 to 15 feet are shewn, being from 25 to 28 feet at high water. In the anchorage at Poolbeg, depths of from 13 to 15 feet. On the Ford Bank depths of 10 to 11 feet or 23 to 24 feet at high water, where Giles found only a narrow passage of 7 feet depth, and Bligh only 4 feet at low water, the channel being now wide and direct. In the anchorage westward of the Ford, from 14 to 17 feet, or 27 to 30 feet at high water, the channel also being wide and direct. Abreast the entrance of the Pigeon-house basin, a depth of 9 feet same as in 1819; at the western angle of that basin 10 feet, instead, as in that year, of 5 feet, and from thence to the quays of Dublin a channel from 8 to 10 feet, or 21 to 23 feet at high water, instead of the extensive shoals crossing the channel, having not more than from 2 to 4 feet upon them. The rise of spring tides being from 12 to 14 feet, it will be manifest that the river has been made navigable at half-flood for a class of vessels which formerly could not, when laden, have passed at high water, a beneficial result brought about in a two-fold manner, as pointed out by Mr. Halpin, in his valuable Reports on the harbour, to which I am indebted for much information; the improvement of the outer entrance or bar channel having been produced by the direction and force given to the ebbing tide by the pier projected from the Clontarf shore, while the deepening in the river between Poolbeg and the quays was made chiefly by steam dredging, aided by the increased velocity of the current. There are only a few minutes' difference between high water at the bar and at the quays. The first steam dredge was used in 1832.

Looking to the magnitude of the works completed for the improvement of the port—the difficulty of attaining the object

in view—the value of the ground reclaimed forming the North and South Lotts, the advantage to the drainage of the city by the increased depth of the outfall, the whole must be considered not only to have justified the large expenditure incurred, but also to reflect much credit on the engineering skill brought to bear upon it.

Speed's map, published in 1610, attached to Whitlaw's History of Dublin, shows that there was only a small portion of the Liffey embanked on the south side, and the whole of the present line of quays on the north side was overflowed by the tide, except a small part at the King's Inns, then a monastery. In a north-easterly direction the marshes existing where the Custom-house now stands, were covered by the tide up to the site of Annesley bridge and to the locality where Aldborough House now stands, at the foot of Summer-hill. The whole of the strand from Ballybough bridge to Baggot Rath was also covered by the floods of the Tolka, Liffey, and Dodder, until confined by the North and South Walls.

The conclusion having been early arrived at that the port of Dublin was not likely to be rendered at best more than a tidal harbour, with its inseparable delays and dangers, and that an entrance harbour sea-ward of the bar was indispensable, Dunleary was selected, after a great deal of deliberation, as a proper place for a work of that description. In the year 1755 a petition was presented to Parliament, subscribed by the merchants of Dublin, praying for a grant towards the erection of a pier at Dunleary; the estimate was stated at £20,100. The project having been approved, a sum of £5,000 was voted in that year to Trustees nominated for carrying on the works, to be accounted for by them to Parliament. A grant for a similar amount was made in 1757; and in 1759 a further application was made by the Trustees, stating that 361 feet in length of the pier were then finished, that a considerable quantity of materials had been provided for

its further extension, and that valuable ships laden with sugar had been saved by it, when in great distress. £3,000 only were then granted. In 1761, the Trustees having again applied for aid, a Committee of the House reported that the money granted had been laid out with economy, and that a sum of £9,322, to make up the original estimate, was still necessary for completing the work. On the testimony of Mr. George Glover, Surveyor of Kingstown, it appeared that no less than thirteen vessels had been saved by it, several of them richly laden, and that fifty-eight vessels had discharged their loading there within the last two years. A further sum of £3,000 was then granted, and in 1763 £1,000.

The Trustees having experienced much opposition from some members who were adverse to all Parliamentary grants, determined to free themselves from further responsibility, and applied for the sum of £1,500 only, which they were assured by Major Vallancy of the Royal Engineers, would be sufficient, and who undertook to complete the pier for that sum, with the unexpended balance of the former grant, the work was accordingly brought to a close in 1767, short of the original design, for a sum of £18,500.

This record has been here transcribed as an example of a questionable description of Parliamentary control, which has survived to the present time, often leading to greatly increased expense, and many other evils, by the protraction of the period of completion, owing to the mistaken economy of pinched annual grants.

The harbour was formed by a single pier 33 feet wide at top, extending 423 feet in a north-westerly direction, enclosing a convenient space with a good strand for beaching on the land side, towards the south there is also a boat slip. The head is a segment not very correctly built, having a radius of 30 feet, and batters from 4 to 6 inches to the foot. At the head there is from three to four feet depth at low water.

With reference to an asylum harbour, Sir Hyde Page, in his Report of the year 1800, having, as therein stated, taken into consideration the great difficulty of making the port of Dublin a good one, under any circumstances, seeing that the bar could not be passed except at certain times of tide, and that a great number of vessels were wrecked in Dublin Bay, for want of a port with deep water to run for at any time, proposed that Dalkey Sound should be sheltered against the east, and points of the compass from the south to south-east, by uniting Dalkey Island, Lamb and Maiden Islands, by a rough wall or breakwater, and by extending, from the south-west point of Dalkey Island, a pier to a sufficient distance into Killiney Bay, in a south-westerly direction, in order to afford better shelter to the anchorage.

He also proposed to carry out a pier into deep water at the south side of the Bay, at Sandycove point, from which a ship canal might be made to communicate with the Grand Canal new floating docks. A short pier was also to be constructed from the rock of Sandycove point, to be extended about 400 yards into the bay, nearly parallel with the course of the tides. The proposed level of the water in the ship canal to be the same as that of the Grand Canal harbour. A basin for ships to be constructed near the Grand Canal, and the same level as that of the Canal harbour was to be carried by an aqueduct over the river Dodder, near Milltown, and from thence on the same level across Mount Merrion Avenue, passing near the Stillorgan Obelisk, and Monkstown Church, to the falling ground near Sandycove point, where locks were to be made to communicate with an entrance basin, and with the deep water in the bay. From the ship basin, near the Grand Canal, a branch was proposed to communicate by lock with the new docks and the Liffey.

Sir Hyde Page, at the same period, directed his attention to Howth. He recommended it as a good site for a Packet

station, and proposed that a harbour should be formed by constructing a pier to extend one-third of the breadth of the sound, towards Ireland's Eye, and from the latter towards Howth, to protect the entrance from the north; deepening to Baldoyle water was also a part of this project. The cost of the piers was estimated at £86,400.

Sir Hyde Page took occasion, during his inspection, to condemn a project of the Grand Canal Company, proposed by Mr. Jessop, and approved by their Engineers, Captain Evans, and Mr. Kilally, to make a ship canal from their new docks to Old Dunleary harbour; the objection having been, that it could not be carried from deep water, as at Sandycove, thus involving the necessity of deep sinking under low water mark. He also disapproved of two other plans of ship canals, which appear to have been a favourite project of the day, one by Mr. Vavasour, from Dalkey Sound to the Grand Canal Docks, the other by Mr. Thomas Rogers, from the Liffey, at the North Wall, by the North Strand, to the western end of the North Bull, opposite Clontarf, and thence through the Isthmus of Howth, to connect with a harbour proposed by him between Ireland's Eye and Howth. A large portion of the Bull was to be taken in by an embankment and reclaimed, and that tract, with the land included within the southern bank of the canal, amounting to 3,200 acres, was estimated to be worth, after the lapse of three years, £3 per acre, which at twenty years' purchase would give £102,000, being £69,460 more than the canal and sea embankment would be completed for. In this final notice of these often-mentioned sand-banks it will not be out of place to observe as to their designation, borrowed from the supposed resemblance of the noise of the tide passing over them, to the roaring of bulls, that whether due or not to native imagination, it has a classic precedent in the Iliad, where a similar comparison is made by Homer, with reference to the resounding of the sea.

From the great expense of Mr. Rennie's project, before referred to, for the improvement of the port, with the small comparative advantages to be derived, he was induced, as others who had preceded him had done, to consider whether any more eligible and effectual plan could be devised, at a less expense, than what he had already proposed.

For that purpose he stated in his Report that having carefully examined the north side of the Bay, and round the Green Baily, to the entrance of the harbour of Baldoyle, and also the south side, and round by Dalkey Island to Killiney Bay, there appeared three situations worthy of attention, namely, Sutton Creek on the north side, Dunleary and Sandycove on the south side, and as to a harbour at Howth, in the sound between Ireland's Eye and the main land, with a canal to Dublin, it did not seem to him sufficiently inviting to warrant a very strict examination, as he was of opinion that the harbour could not be made permanently deep, and that the canal would be silted up.

The sound, he observed, was extremely useful. There was deep water round the whole island, and if vessels could get to it in stormy weather, they would always find shelter in the wake of it. He was therefore of opinion that no money should be expended on this situation, nor on the improvement of Dalkey Sound, as it was dangerous for vessels to take shelter there in the winds blowing from the east and southward, on account of the proximity of the entrance to a rocky lee shore, these points of the wind being the only ones in which the harbour could be of any use to a vessel embayed, as in easy weather they could ride in the Man-of-War Roads, until the tide suited.

The consideration then came, which of the three situations named within the bay would best answer. The plan of an entrance harbour at Sutton Creek, proposed by Captain Perry in 1725, was approved of by Mr. Rennie, with some modifica-

tions. Perry's scheme was to construct a harbour on the north-west side of the Hill of Howth, by building a pier from the south point of the North Bull, of about one thousand two hundred yards in length, parallel to the shore, where the depth is about 13 feet at low water, and another pier from the mainland opposite to its extremity, of about three hundred and fifty yards in length, leaving an opening of one hundred and fifty yards wide between this and the west pier, as an entrance to the harbour so formed. At the head of this harbour he proposed to construct a sluice, and from thence a canal within the North Bull, along the Clontarf shore, for boats and gabbards to navigate to the Liffey at Ringsend, having a weir or overfall from Ringsend to Clontarf Island, for the purpose of discharging the floods of the rivers Liffey and Dodder and the Ballybough stream. The whole of these works estimated at only £36,606, were in substitution of a plan proposed by him in 1713, and condemned, but not until its impracticability had been actually tested, as already noticed.

Mr. Rennie recommended that the harbour of Sutton should be made sufficiently large to contain about 260 sail of ships, in a depth of water from 12 to 14 feet at the entrance at low water of spring tides. At the head of this harbour he proposed a basin of about 5 acres, to hold about 40 sail of ships, having a sea and communication lock, and from thence a ship canal, about 80 feet wide at bottom, 160 feet at water surface, and 20 feet deep, to be made to the east wall of the North Lotts at Dublin, and there to establish wet docks of such extent as the trade might require, to be supplied with water from the Royal Canal.

The expense of this harbour and canal was estimated at £657,157, to which should be added £150,000 for the docks, so that the whole expense of the plan amounted to £800,000.

The second situation referred to within the Bay was at Dunleary, and for it a plan had been proposed by Mr.

Jessop. This plan consisted of a harbour to be constructed at Old Dunleary, having from 12 to 14 feet depth at low water, but capable of holding only 100 sail of vessels, the situation not admitting of being much enlarged, without a very considerable additional expense; at the head of this harbour a basin of 5 acres capable of holding about 40 sail of ships, with a sea and communication lock, was proposed, and from thence a canal to be made to the Grand Canal Docks.

The whole expense of the canal basin and harbour, as estimated by Mr. Jessop, and approved of by Mr. Rennie, with a modification similar to that proposed by him for Sutton, amounted to £489,734, not including the enlarging of the Grand Canal Docks.

With reference to the third situation, Sandycove, lying about a mile and a quarter eastward of Dunleary, and where there is deeper water, Mr. Rennie considered its situation in the bay peculiarly eligible for the entrance of vessels riding either in the Man-of-War Roads, when storms came on, or for inward-bound vessels from the channel; he also considered it equally convenient for vessels proceeding to sea. He reported that the situation admitted of a harbour being constructed similar to that proposed for Dunleary. But the ground from thence to Dunleary being high and rocky, the making of a canal for so short a distance, to join with that proposed to communicate with Dublin, would amount to £100,104. The ends of the proposed piers being also in very deep water, namely, four fathoms at low water, would render them very expensive, so that the whole expense of the plan would amount to £705,054, being £49,184 more than at Sutton Creek, and £215,320 more than at Dunleary.

Captain Joseph Huddart having been consulted on the nautical questions involved, admitted the eligibility of the three situations above described, but concurred with Mr. Rennie in giving the decided preference to Dunleary, which,

from the description, will be seen was a project distinct from the present asylum harbour at Kingstown, in deeper water than that constructed in 1765.

INLAND NAVIGATION.

THE importance attached to the supplying of Dublin with native coal gave rise to many extensive projects for the promotion of that object. The communication between the collieries at Drumglass, near Dungannon, and lough Neagh, was effected by the Tyrone navigation, or Coal Island Canal, leading into the Blackwater river, and from thence by the Maghery Cut into the lough from which the river Bann and the Newry navigation conduct to Carlingford lough.

The Newry Canal extends 3½ miles from the Victoria sea-lock at Doyle's Hole to Newry, and from thence to the navigable part of the Upper Bann river, the whole distance to lough Neagh being 25½ miles Irish, 9 miles being in the bed of the river. The summit is 65 feet above the level of the sea, and 22 feet above lough Neagh, making a total rise and fall of 87 feet in 24 miles, equal to 3⅝ feet of lockage. There are 13 inland locks, varying in size from 63 feet 10 inches by 15 feet 1 inch to 15 feet 3 inches in width, 5 feet to 5 feet 6 inches on sills, in the normal state of the navigation; width of canal, 40 to 45 feet at water line. The summit level is supplied by a feeder from the Cushe river, taken at Tanderagee bridge; there is also the reservoir of lough Shark, about 75 acres area, which is, itself, fed by a stream flowing from Loughbrickland; this, however, is stored up in summer for flax mills when it is most needed for the purposes of the canal. The Bann seldom floods the neighbouring lands since the completion of the lough Neagh drainage. There is, at the entrance of the lough, a bar, having over from 4 to 5 feet of water in summer, but as it

shifts with the varying impulses of the current, frequent dredging would be required.

The adoption of different plans, and the rejection of them when partly executed, led to great expense in the execution of the works of this navigation; some short details of the difficulties of which, it is presumed will not be amiss in illustration of the state of the engineering of the period, not belonging to a native school though practised in Ireland. The undertaking was commenced in 1732 between Newry and the river Bann, under the direction of Mr. Richard Cassel, a German Engineer, who was appointed by the Commissioners of the Board of Navigation, and who built the first stone lock erected in Ireland. Mr. Cassel, not having given satisfaction, was replaced by Mr. Steers, a Liverpool Engineer, under whom the canal from Newry to the deep water of the Bann was finished in 1741. The portion between Newry and Fathom Point was not completed until 30 years later.

We learn from a report in 1750, of Mr. Acheson Johnston, Undertaker and Engineer of the Newry Canal, positions then not incompatible, that of the fifteen locks on the canal, twelve were in good order, two of the remaining three were built nine years previously on a French plan, with pipes in the side walls instead of sluice tunnels; these were subject to burst and were out of order. The splays or fronts and tails of the locks were built of brick and were mouldering away, and the waste of water was such, that the levels, full over night, were dry in the morning. The third lock was built of common rough stone, and the water had pooled behind it in several places. A mile and a half of the upper level, next Poyntz Pass, was so narrow that two boats of burthen could not pass each other.

As to the then state of the navigation from lough Neagh through the county of Tyrone towards the coal pits, Mr.

Johnston stated that the navigation was continued out of the lough by the Maghery Cut for nearly three miles in the bed of the Blackwater river, and that a canal was carried from thence 3 miles 38 perches to the town of Coal Island, that it had three locks upon it of stone, and that it should be carried further towards the collieries of Drumglass and Stewartstown.

The Maghery Cut was made across the isthmus of that name for the purpose of avoiding the bar at the mouth of the Blackwater, having upon it 1 foot 10 inches of water in summer.

The continuation of the canal, on Mr. Acheson Johnston's plan, having presented some difficulties, Mr. Christoper Myers was appointed to succeed him as director of the works, in 1762. He proposed to make a canal of sufficient size to enable vessels of 100 tons to sail from Newry to the collieries. He began at the colliery basin, but he had not made much progress when he found that the expense would be so great, that he recommended the giving of it up after having made the *experiment*, as he called it, of excavating a portion of the line and building a lock 125 feet long and 22 feet wide. The estimated cost of this canal, to extend 2½ miles, from the termination of the old canal to the colliery, was £26,000. The intention of making it having been abandoned, Mr. Davis Duckart, an English Engineer, who had been long in the Sardinian service, was appointed. He made a communication between Drumglass and Coal Island, a distance of about three miles, by the formation of four pools, or levels, at different elevations, 4 feet deep and 24 feet wide, for vessels of 12 tons burthen: between each level, was an inclined plane having beams of timber laid down with castors fixed on them. These contrivances, called dry hurries, were intended for small laden vessels to go down with the help of a crane and rope to prevent their running too fast, and also to draw up the empty boats.

This system of narrow canals, inclined planes, and wheeled boats of about 4 feet in width, was recommended by Fulton, as useful in facilitating the navigation of the great rivers and lakes of America, and was intended as an improvement on the plan of the Chinese, who, being ignorant of the contrivance of a lock, use, at the present day, inclined planes, up which their boats are pulled by a great expenditure of manual labour.

In the year 1774, Mr. Jessop was consulted as to the mode of constructing the inclined planes between the different reaches of the canal, and he having had some doubts as to the mode of proceeding, had recourse to the advice of Smeaton, who, in his reply, as given in the second volume of his Reports, observes—"That, as the bulk of the expense had been incurred in making the reaches of the canal, the experiment of Duckart ought to be carried out in order to test its applicability to other places." Smeaton adds—"If the scheme does not, on trial, answer, a railroad of timber, after the manner of those at Newcastle and Whitehaven, would be preferable in such a situation, either to a canal or a gravelled road, especially as it could be done with a length of two miles, and most of the way down hill, so that the loaded waggons would go down by their own gravity, and the horses would have nothing to do but to draw the empty ones back, which, in a rise of 192 feet in two miles, would be easy work." We, at this time, cannot understand how a most expensive and complicated system should be preferred to the simple and effective contrivance of an inclined plane.

Mr. Duckart also proposed and partly executed a subterranean navigable canal, with ventilating shafts to be made to answer as a sough or drain for all the collieries, and to communicate with the old navigation, at a cost of £26,900. A Mr. Hamilton Bury, an Engineer, who had been contractor on the works of the Nore, gave evidence before a Committee of the House of Commons, as we do now-a-days, that the

work could be executed for the estimate, but, as also sometimes happens with us, it was not so done, and was, after the expenditure of a considerable sum of money, abandoned about the year 1775.

Mr. Richard Owen having been called on for his professional advice in 1787, found the hurries constructed by Mr. Duckart out of order: he recommended the gradient of the inclines to be lessened, and the beams and rollers to be replaced by a road made of broken stone and gravel. In this state matters remained as long as unchecked dilapidation permitted.

With reference to that portion of the navigation from Newry to Fathom, which, as before stated, was not finished until thirty years after that between Newry and the Bann, a contract was entered into in 1758, for its execution, with Mr. John Golborne, Engineer, of Chester, who, after working at it for a year, abandoned it, and returned to his own country. After Golborne's departure, recourse was had to Mr. Christopher Myers and Mr. Thomas Omer, in conjunction, by whom, what was done by Golborne, was condemned, and considerable sums were laid out by them up to 1763, without, however, producing any desirable result; for, on inquiry before a Committee of the House of Commons, in 1767, it appeared that the work was wholly inoperative.

Mr. Christopher Myers, who, at that period, was architect to His Majesty's Board of Works, having been examined, stated that so much of the work as was carried on by him, in 1762 and 1763, was in accordance with the plan approved by the House in 1759, that he had advised 6 feet depth instead of 9 feet, as executed, and that he had offered in the first instance to contract for the whole for £18,000, provided half the amount was then granted, and the remainder in the following session, but as £5,000 only was granted, he refused to be responsible for its completion.

Mr. Thomas Omer, who was a Dutch Engineer, having been examined as to the insufficiency of his plans, excused himself by stating that he knew they would not answer; that he had made them by order of the Navigation Board, and that he proceeded while the money lasted.

As this was by no means a solitary instance of the misapplication of public funds, the management of the Navigation Board fell into disrepute; and that body, which commenced its functions in 1730, under the 3rd Geo. II., was dissolved by the 27th Geo. III. in 1787, and a system of granting aids to private undertakers, in proportion to their subscriptions, was thenceforth adopted under the provisions of that act. The navigations thus transferred were those of Newry, the Boyne, the Barrow, the Shannon, and Tyrone. The company for carrying on the Limerick Navigation had been already incorporated in the year 1767, and the Grand Canal Company in 1772. To these undertakings grants in aid were made from 1789 to 1800, and in the latter year a sum of £500,000 was granted to be applied to the system of navigation generally, and for the improvement of the Port of Dublin in particular, under the supervision of a board of five directors.

The management of a body so numerous and ill-constituted as the old Navigation Board, consisting as it did of eighty-six persons, twenty commissioners having been particularly named for each of the four provinces, with the Chief Governor, the four Archbishops, the Speaker for the time being, at their head, carried with it from the beginning the germ of its own decadence, and in its failure could have suggested no other feeling than that of surprise at its having been accorded an existence of fifty-seven years, during which twenty-three different extensive projects were undertaken, but not a single one brought to completion, with an aggregate expenditure of £600,000. But bad as the administrative part of the manage-

ment must have been, the executive was still worse, and its details go far to show that there were other causes of failure than that generally received, of a prevalent system of jobbing, an imputation from which to relieve the country, even at this distance of time, is a duty not too late to be performed; the inference from the statement of facts being left to others to draw, keeping in mind that the Engineers employed during the period referred to were not Irish.

About the year 1780 the canal was extended three miles further to Fathom, to accommodate the ordinary run of coasters of about 120 tons, there being 9 feet depth of water on the sill, and 21 feet breadth of lock. In 1789 Mr. Richard Evans, Civil Engineer, reported on the state of the navigation, and gave plans for its improvement, but without having been attended with results, nor does any renewed attention appear to have been given to the subject until the year 1800, on the vesting of the Tyrone Navigation in the newly constituted Board of Inland Navigation, when Sir Thomas Hyde Page made a proposal to extend the canal from Fathom to Rice's Bay, opposite Warren Point, at a cost of £136,000. On entering into possession at the above period the Directors-General found that the works, constructed at a cost of £114,220, had been allowed to fall almost into a state of ruin, and they were obliged to expend £20,730 on the Tyrone Navigation which had been abandoned, and £53,379 on the reconstruction of the Newry Navigation, in deepening the levels and rebuilding most of the locks; £15,043 of the latter expenditure having been received from tolls. Up to 1812 these works were executed under the direction of Mr. Brownrigg, who was the first native Engineer appointed.

The widening of the sea lock at Fathom, and the putting in of a stone platform and sill—the first instance of that mode of construction in Ireland, was subsequently executed at an

additional expense of £5,000, under the superintendence of the same Engineer.

In 1828 Mr. Alexander Nimmo having been consulted, reported in favour of deepening the natural channel of the river, so as to secure 14 feet depth at neap tides all the way up to Newry. For this his estimate was £98,568. In 1830 Rennie, Killaly, and Brownrigg agreed generally in their Reports as to the propriety of making a canal from Fathom to the deep water at Doyle's Hole, with a ship lock there, and the deepening of the natural channel at Narrow Water, as recommended by Rennie.

In the year 1831 the Newry Navigation Company was incorporated by Act of Parliament, and they were authorised to levy tolls on condition of their expending not less than £80,000, in seven years, in keeping the works in repair, and in the extension and improvemet of the Navigation, or in default, the works to revert to the Commissioners of Inland Navigation, on payment of their value to the Company. It appears that up to 1848 nearly £50,000 were expended by the Company in deepening and widening the channel of the river from Doyle's Hole to Narrow Water, and from thence to Warren Point, that a steam dredge had been purchased for that purpose, and that a contract had been entered into amounting to £40,000 for extending the canal along the western side of the river, from Fathom to Doyle's Hole, and the erection of a ship lock, all of which have been since executed.

The canal has been extended one mile and a-half from Fathom—the old lock there taken up, and the Victoria lock designed by Sir John Rennie, and superintended by Mr. John Ramsay, Civil Engineer, was opened for traffic in the year 1850, at a point in the river three and a-half miles below Newry, known as Doyle's Hole, where there is 76 feet sounding, affording safe anchorage to vessels waiting for the opening

of the lock, which is 220 feet long and 50 feet wide, having 17 feet 9 inches of water on the upper sill into the canal, and 7 feet on the lower sill at low water of spring tides. The masonry is of a very superior description, consisting of massive granite blocks, with some limestone, from the neighbourhood of Carlingford. The whole was erected at a cost of £25,000, including two pair of gates made of mahogany and teak; the estimate of the latter was £3,500.

The new part of the canal is 140 feet wide at water surface, and 80 feet wide for the remainder of the distance to the entrance of the Albert Basin at Newry, which does not admit vessels of more than 14 feet draught, rendering it necessary to lighten them in the canal, where the depth is 17 feet. From Victoria Lock to Warrenpoint Roads, a distance of two and one-third miles, shoals of rock and sand have been removed by blasting and dredging, and river walls constructed, confining, and in some parts enlarging, the tidal scour.

The Belfast Railway competes with the Newry Canal to Portadown, running close alongside in many places; however, the communication by means of lough Neagh with the Ulster, Coal Island, and Lagan Canals, enables this navigation to maintain the struggle. The tonnage register entered seawards, on an average of the years 1858 and 1859, was 78,051 tons, and the receipts from ballast and tolls, both sea and inland, amounted averagely to £6,074.

With reference to the attainment of the object which at the outset prompted the undertaking of the Tyrone and Newry Navigations, namely, the supplying of Dublin with coal, it appears that in 1748 a company, consisting of a few wealthy local proprietors, was formed, and a Mr. John Fletcher, an English gentleman of great experience, was brought over, who, on examination, was so convinced of the great capabilities of the Drumglass and Stewartstown collieries that he joined the partnership, and sent miners and artificers from

England. He put up a large water engine, worked by a rivulet, and constructed a sough or underground drain, 1,200 yards in length, but these means of unwatering having proved to be inadequate, a sum of £2,000 was granted by Parliament in 1784 to John Staples and James Caulfield, Esquires, for the purpose of erecting a steam engine, obtained from an English manufacturer, who was delayed in fulfilling his agreement by the drought of the season depriving him of mill power. This was probably the first steam engine introduced into Ireland; and the fact of a factory of that description being wholly dependent on water-power, shows the stage to which that branch of manufacture had at the time arrived in England.

The catalogue of successive failures may be summed up by the report of Mr. Francis Trench, Secretary to the Directors-General in 1812. He informed that Board that the price of coal at the pit was sixteen shillings per ton, and the lessee expected to get them to Dublin for twenty-six or twenty-eight shillings, including the bounty of two shillings per ton. Mr. Trench did not consider it was the interest of the lessee to send them there, as they were of a very indifferent quality, small, swift, and without any of the bituminous quality to make them adhere. He found from actual trial, at a house in the neighbourhood, that a good fire could not be made of them without the addition of turf; at another house they burned English coal, at thirty shillings per ton, which he considered was much cheaper, being better. Having been informed that there was a superior description at Coal Island, he visited that place; the pit was about 60 feet deep, and the seam reported to be six feet, but it could not be raised large; on the whole it was by far the worst coal he ever saw, and in his opinion was not worth working.

At a later period the field was occupied by two companies, and notably by the Hibernian Mining Company in 1829, but as this branch of the subject has been taken up by Sir Richard

Griffith, in his Survey of the Tyrone Coal District, it would be more than superfluous to pursue it further here.

More details may, at first sight, perhaps, appear to have been entered into with reference to the Tyrone and Newry Navigations than the immediate interest of the subject deserves, but their chequered progress is so illustrative of the empirical character of the engineering of the time, that in an historical point of view a particular notice of the progress of these undertakings, in connexion with the professional persons employed, can not be considered out of place, the more so as it has been customary to attribute the failure of every thing in Ireland to native incompetency, or yet worse, to jobbing, whereas the facts show that the unskilfulness was not theirs, and that the spirit of enterprise was marred by the general want of professional knowledge.

CARLINGFORD LOUGH.

This lough is a natural inlet, extending eight miles from the bar at its entrance to Warren Point, and affording upwards of one thousand acres of good anchorage, but subject to a rapid run of tide, and to heavy squalls from the Mourne mountains. According to the nautical survey of Captain Mudge and Lieutenant Frazer, made in 1831, the soundings at low water of spring tides are but 9 feet on the bar, the rise of springs 18 feet, and of neaps 12 feet. Once, however, the bar is crossed there are six miles in extent of the lough, having not less than four fathoms depth, the remaining two miles to Warren Point are navigable at tide time by vessels of 18 feet draught. The entire of the navigation from lough Neagh to Carlingford bar is about thirty-two miles in length.

Warren Point lies six and a half miles below Newry. A tidal basin was constructed there, at the public expense, in 1767, but has since been enlarged, and quays built by the

owner of the soil, the Marquis of Anglesea, who levies dues for their use. A patent slip has also been built, capable of admitting vessels of 750 tons, being the tonnage of the largest steamers of which Warren Point is the station.

Carlingford Bay in its position, half-way between Kingstown and Belfast lough, distant from each other 100 miles, offers great advantages for refuge in easterly winds, if its bar were removed, the practicability of which, by dredging, has been shown by the soundings made in 1835 by Mr. Ramsay, Resident Engineer, who reported it to be an original formation, composed of blue clay, mixed with moderately-sized boulders. Mr. Robert Tuthill, the present Engineer of the Newry Navigation, states that a passage of about half a mile in length, of easy access, and leading into four fathoms water, could be readily made by dredging. A deep passage through the bar was discovered when the Commissioners for inquiring into Harbours of Refuge were examining it in 1859, but it is tortuous, and a square-rigged vessel would find it difficult to beat in, unless in a leading wind, nor could it be attempted, under any circumstances, at night.

Captain Washington, R.N., has observed, in the second Report of the Commissioners on Tidal Harbours, that the rendering of this bay a harbour of refuge, by deepening the bar to at least 18 feet at low water of springs, would be well worth a large expenditure, on account of the very great number of vessels navigating the Irish Sea, and having no other harbour between Kingstown and Belfast Lough, unless, perhaps, Strangford, that can be taken in an easterly gale, but under such circumstances the latter would be difficult of access, there are not, however, wanting available intermediate positions on the coast, as at Skerries, county Dublin, Ardglass and Clogher Head; the two former could be made of great service, at a moderate cost,; and Clogher Head, within eight miles of the bar of Carlingford, possesses considerable capabili-

ties for an asylum harbour, a large sum, however, would be required to render it effective.

Judging from Norie's sailing directions for the Irish Sea, the approach to Carlingford Bay, outside the bar, is beset with danger; it has, however, been again brought into notice as a harbour of refuge by the Commissioners for inquiring into harbours of that description in 1859. They recommend that a channel, six hundred feet in width, should be dredged through the bar, at a cost of £50,000.

LAGAN NAVIGATION.

THIS navigation extends twenty-eight miles, from lough Neagh to the quays at Belfast, from whence, to the first lock, there are two miles in the tide-way. The summit level, eleven miles in length, is 112 feet 6 inches above the Belfast lough, and 71 feet above lough Neagh. There are twenty-seven locks in all, of which seventeen complete the rise between Belfast and the summit, four of them, in close proximity, called the Union locks, ascend at a distance of thirteen miles from Belfast, from the river to the summit whence the navigation to the lough is artificial, about three-fourths of the whole length being similarly circumstanced. The summit level is carried over the river Lagan six miles three-quarters from the Union Locks, by an aqueduct of four arches. The chambers of the locks are 65 feet 3 inches long, and 15 feet 6 inches wide, with 6 feet 6 inches depth on the sills in winter. The locks between Belfast and the summit having been built of red sand-stone, became so dilapidated that large pieces had to be cut out of the side walls, and replaced with fire-brick, but basaltic stone having been used at the lough Neagh side, no such reparation was found necessary. The levels of the respective reaches are maintained by pen weirs, and over-falls constructed on the usual principle,

the former have from eight to fifteen sluices in each of them respectively. The artificial cuts have a breadth at bottom of 30 feet, and 51 feet 6 inches at water surface, and, except in very dry seasons, barges drawing from 5 to 6 feet pass freely, carrying sixty to seventy tons burthen.

This is one of the many projects commenced under the auspices of our native legislature, defective in design, and consequently attended with ever-recurring impediments during its construction, aggravated by the absence of sufficient means for completion, under unfavourable circumstances. In the year 1753 the Board of Inland Navigation was empowered by the Act 27th Geo. II., c. 3, to make the river Lagan navigable, and to open a passage by water between the town of Belfast and lough Neagh. In order to carry out that object, additional duties were levied by consent of the inhabitants, on certain articles brought for consumption into the district through which the navigation was to extend. The works were commenced soon after the passing of the above-mentioned Act, and were in the year 1763 advanced in their construction so far as to have allowed a boat of forty tons to pass from Belfast to Lisburn, a distance of eleven English miles, open from that period for public traffic.

The following, with reference to this subject, appears in the Reports of the House of Commons for the year 1767. Mr. Thomas Omer, Civil Engineer, having been examined, stated, that "between Belfast and Lisburn weir, there had been built twelve locks and eight pen locks, upon which were expended about £1,000 each; that it would require one more large pen lock in the tide-way near Belfast, in order to admit of a passage for boats at neap tides, this would cost at least £1,000, and would complete the number of locks necessary between Belfast and Lisburn weir. That the digging yet to be done on the trackways would require £500, so that £1,500 would complete the navigation from Belfast to Lisburn weir

for vessels of from forty to fifty tons burthen. That from Lisburn weir to Spencer's bridge, a distance of about six miles, would afford sufficient work from that period to the next session, and would require £3,000 to complete, supposing it to be carried on in the bed of the river."

The Committee resolved that it was their opinion it would require £4,500 to complete the navigation from Lisburn weir to Spencer's bridge, and that the £4,000 granted in the last session had been accounted for.

The works above referred to by Mr. Omer having been completed at an expense of £43,304, arising from tolls and grants, and there being no corporate funds at command, the extension from Spencer's bridge to lough Neagh was carried out under the direction of Mr. Owen, Civil Engineer, at an expense of £60,000, by the munificence of the Donegal family, to whom the navigation belonged until the early part of the present century, when it was purchased by a company of merchants, by whom several necessary improvements were effected, amongst which may be enumerated the making of the artificial cut between the fourth and fifth locks. From this level, also, five tunnels were constructed, opening into the river with valves acting only when the water in the river is low. An additional lock was made in the tide-way about a mile nearer to Belfast than the previous No. 1 lock, in order to facilitate the passage of boats in neap tides; and the degrading effect of the river on some parts of the canal was remedied by driving piles to support the banks. These improvements were effected between the years 1809 and 1820.

Not less than eight acts of parliament, commencing with the 27th Geo. II., in 1753, and ending with the 6th and 7th Vic., in 1843, conferring powers to raise money to complete this undertaking, were obtained; and yet much that was felt to be desirable remains undone. The money authorised to be borrowed by the act of 1843, has not been raised for the

proposed extension of the canal to Belfast, and consequently the difficulty of entering it when the wind blows from a certain point remains unremedied, but lighters can pass freely at all other times of high water at neap tides. The navigation, taken generally, is in fair working order, and the shareholders have been receiving a small dividend for the last few years.

There were two great errors in the original plan of this undertaking, the first being through an idea of economy, making the river with a fall of 80 feet, part of the navigation between Lisburn and Belfast, the rapidity of the current having been a constantly recurring cause of injury to the banks, and interruption to the trade; the second error was the insufficient supply of the head level. For remedying the first, Mr. Robert Whitworth, having been in Ireland in the year 1800, was consulted, and recommended the abandoning of the river as a navigation, and turning it into the head level for supply, but the valuable milling interests would have been so much injured by the carrying out of his plan, that it was abandoned and palliatives only resorted to.

Mr. Mullins, in his Treatise on Inland Navigation, published in 1823, observes that—

"This navigation partakes of the defects of its time, both as to design and cost of execution. Continuing in the beds of rivers, even when running through flat countries little subject to floods, is found generally to be inferior to parallel cuts; but in those rivers subject to a sudden rise in their waters, the idea of making them permanently navigable, at a remunerative cost, is almost hopeless; the tendency they have to raise their beds, the constant shifting of their channels, the wear and casualties to which they are so peculiarly liable, and the consequent cost of maintenance are considerations of such weight, that, if duly appreciated, the improvement of river navigations, except in few instances, would not be undertaken."

These theories, he continues—

"Applying almost universally, are realized in our rivers which have been rendered partially navigable by an outlay far more than sufficient to make parallel lines of canals through the districts in which they respectively

run; the river courses being in the latter case left free for the performance of such necessary operations as deepening their channels, and the removal of those obstacles which occasion the constant overflowing of their banks for several months in each successive year, to the great deterioration, if not destruction, of thousands of acres of what would otherwise be the best land in the country."

Mr. William Chapman, with whom Mr. Mullins had the advantage of frequent communication during his residence in Ireland, makes observations of a somewhat similar nature in his Report, dated 1795, on the proposed canal between Newcastle-on-Tyne and Solway Firth. He rejects the plan of making the river navigable above the tide-way, on account of its liability to floods, and the consequent formation of shoals, owing to the nature of the bottom; and he observes, that flush weirs or any other means of keeping the channel open in dry seasons, would be attended with great expense; that the river could not be thrown into a succession of still pools, except at an outlay, for the construction of locks, exceeding that of a canal cut through the land; and as to forming a navigation partly composed of a canal, cutting off the sudden bends of the river, and partly of the river itself, it would partake of the inconvenience of making the river the chief line of communication, and would be subject to great interruption and danger from floods. In consequence of this the undertakers should either be content to have their works occasionally overflowed, or they must, at the upstream entrance of every part of the canal, where it leaves the river erect, a guard lock of a height equal to that of the floods. The expense of every such lock, with its accompanying weir, and of the raised trackways along the navigable shore, would be very great. Under these circumstances he decided on an independent canal entirely across the dry land.

The conditions under which the improvement of river navigations should be undertaken, shall be referred to when we come to treat of arterial drainage operations

THE NAVIGATION OF THE NORE.

In this undertaking, commenced in 1755, another instance is to be added to the list of failures, as well in the design and construction of the work, as in the ill-considered efforts to supply Dublin with coal, as if the spirit of the day were in accordance with the advice of Dean Swift, to

"Burn everything English but their coal."

The navigation extending from the city of Kilkenny to Ennisteague, a distance of sixteen miles, had been planned by Mr. Omer, in the bed of the river, and estimated by him at a sum of £10,000; but Mr. Ockenden's plan, in which Mr. Omer concurred, for making a canal about four miles in length, and carrying the navigation in the bed of the river the remainder of the distance to Ennisteague, where there was to be a tide-lock, was adopted at an estimated cost of £22,600. Several locks were built 200 feet in length, 21 feet in breadth, and with from 9 to 10 feet fall; also a rimer or flash lock, intended, in time of flood, to preserve 12 feet head of water; at the entrance of the canal into the river, there were platforms of stone work as overfalls to carry off the waste water, and several weirs built to turn the water into the canal. Mr. Ockenden having died in 1761, Mr. George Smith was appointed to direct the works; he reported that boats had passed through all the locks; that £14,000 had been expended, and that it would take £8,471 to carry the navigation from Ballyredingford to Thomastown, within 4 miles of the proposed termination at Ennisteague. After an expenditure of £30,000, it was found that the plan was so ill-devised and executed, that the works were unable to resist the force of the floods, and what with the breaches and subsidence, the whole became an irreparable ruin.

LIMERICK NAVIGATION.

The navigation from Limerick to Killaloe, partly still water and partly in the Shannon, is generally known by the above designation; it is twelve miles in length, and the rate of lockage is 83 feet 6 inches in that distance, or nearly 7 feet per mile. There are eleven locks, none of them alike as to dimensions, and that at Annabeg, although 80 feet long, is not capable of passing a boat exceeding 70 feet in length, owing to the table of the breast gates projecting 10 feet into the chamber. Some of the locks are 16 feet wide, but no boat exceeding 15 feet beam can pass through the whole of them.

The works having been commenced under the direction of Mr. Omer in 1755, were carried on simultaneously with those of the Upper Shannon, between Lanesborough and Carrick, by the Navigation Board, until 1767, when an Act of Parliament was passed incorporating a company of undertakers for making the Shannon navigable from the city of Limerick to lough Derg, above the town of Killaloe; and Mr. William Chapman was appointed their engineer; the works of the Upper Shannon having still remained under the same control as before. From 1767 to 1800 upwards of £25,000 were expended, of which £16,000 were granted by parliament, and a further grant of £6,000 having been applied for in that year as sufficient to complete the works, the Limerick Company were referred by the Government to the Directors-General, who agreed, in 1803, to complete the navigation at the public expense, and to deliver it up to the company on condition of their lowering their tolls as specified. The works were accordingly proceeded with under the direction of Mr. Brownrigg, Principal Engineer to the Board, and when nearly finished, an extraordinary flood, in February, 1809, burst the banks at Erina, carried away the bridge, destroyed the double lock at the same place, and

broke through many other parts of the navigation. The cost of repairing these damages formed a considerable portion of the expense incurred, which, up to January, 1812, amounted to £53,609. The injuries done to the navigation having been repaired, the Directors-General in December, 1810, offered to deliver it up to the company, but they refused to receive it, alleging that the works were insufficient, and great differences of opinion having taken place between the Engineer of the Directors-General and Mr. Donnell, who acted for the company, Mr. John Killaly was called in as umpire. The result was, that the company received £17,000 in consideration of relinquishing their rights, and the navigation has since become public property.

The cost of these twelve miles of navigation, of which five and a-half are in the bed of the river, computed from 1767 to 1810, was £79,559, to this should be added £17,000 paid for the purchase of the rights of the Limerick Company, making in all £96,558. The sum of £27,000, stated in Mr. Killaly's Report of 1812 to the Directors-General, as necessary to perfect the works, was not laid out, and consequently the navigation was left in a very imperfect state, particularly at O'Brien's bridge and Parteen—the trackways incomplete, and the whole liable to frequent damage from floods, and as to the portion between Killaloe and Banagher, not within the scope of the Act of Incorporation of the Company, large boats could not ply, except in winter, on account of the shoals, nor small boats in summer, for want of towing-paths. The principal benefit derived from the undertaking, at that period, appears to have been the supplying of Limerick with great quantities of turf, English coal having been selling there at fifty shillings per ton.

THE UPPER SHANNON.

The original intention of Parliament was to make a communication between the Barrow, the Shannon, and the Boyne, by means of the Grand Canal, as a main trunk, thereby enabling the produce of twenty counties, ten of which lie along the banks of the Shannon, to be carried to the city of Dublin, and with that view the works of the Upper Shannon were commenced simultaneously with those of the Limerick Navigation, and the Grand Canal, in 1755, under the direction of Mr. Thomas Omer, as Engineer. It appears by the evidence, before a Committee of the House of Commons, of a Mr. Edgar, who might have been an assistant to Omer, that in November, 1769, eighty miles of the Shannon had been made navigable between Killaloe and Rooskey. Smeaton states in his Report, dated 1773, that he saw a lock on the Shannon about three miles and a-half below Banagher, which had been in use eighteen years. It was built of hammered stone, and stood very well; he understood it was built by Mr. Omer. A Report by Mr. Jessop in 1794, addressed to the Directors of the Grand Canal, into whose hands the control of the Shannon above Killaloe had passed, throws some light on the then state of the navigation. Mr. Jessop referred to the Reports of Mr. Chapman and Mr. Brownrigg, and to the accurate plans in the possession of the Company, supplied by these gentlemen, giving a minute description of the progress already made, rendering it unnecessary for him to do more than to describe the works appearing to be required to make the river navigable as far as practicable to do so with certainty and expedition. The two great objects that in his view called for this improvement were the collieries, in the vicinity of lough Allen, and the cultivation of an extensive country in ten counties bordering on or near the banks of the Shannon.

As the coal was found on both sides of lough Allen, and at points widely extended from each other, the strata inclining with a gentle dip, he considered the presumption reasonable that there were many thousand acres embraced in the extent of the mine. Experience had proved that it was easily worked, and that, as much of it could be drained without steam engines, it might be got at an easy expense, and was excellent for smelting iron-stone, of which there were immense quantities of the best quality. Here, then, we have the approval of one of the first English Engineers of the day, of an enterprise famous for its abortiveness, and generally attributed to a want of foresight and knowledge, presumed to be peculiar to this country.

The banks of the Shannon being low, and covered with water many months of the winter, Mr. Jessop recommended trackways to be raised two feet in height above floods, and as these trackways should be made on dry land, it would be necessary to cut a channel through the beds of reeds at the verge of the river, wherever they were more than six perches in width; by this means he considered that forty-one miles would have all the benefit of still-water navigation, the lakes, except lough Forbes, being, of course, excepted.

Beginning at lough Allen, he proposed to get rid of the Arigna river, and the immense quantity of detritus it brought into the Shannon, by turning it into lough Allen, through a cut, already made, and only requiring a weir to retain the gravel. From lough Allen he recommended the navigation to be carried, partly by the river, and partly by cuts, to join the canal, a portion of which was made to Battle bridge. From thence to Carrick, we learn from the same document, that there was no material obstruction, except a rocky shoal at Port. The river was from thence good to the Jamestown Canal, which was very imperfect through some deep rocky formation, and was, besides, very crooked; after

the improvement of this canal to near the lock, he recommended the remainder to be deserted, as the river below passes through a chain of lakes very difficult to navigate, and on these no trackway was practicable, but a canal might be made seven miles in length, to join the Rooskey Canal above the lock, which should be raised to the level of the Jamestown Canal.

From the Rooskey Canal the bed of the Shannon to be pursued to a point opposite the Camlin river, which was sufficiently wide and deep, except where a small canal had been cut. From the Camlin river the passage through the Clondragh Canal wanted improvement. At Lanesborough there was a shallow of 300 yards in length, with a fall of 12 inches, partly owing to the obstruction of the eel weirs; to avoid this shallow, a cut was already made with a single pair of gates, this to be converted into a lock. At Athlone the canal wanted deepening and widening. The cut at Shannon bridge, and the canals at Banagher and Cloneenogue required repairs. Below lough Dergh, at Killaloe, there being a fall of 23 feet, the river running over some rocky ground, but generally through gravel, he considered it an object worth inquiring whether this fall might not be wholly or so much reduced as to lower the lake about 18 or 20 feet, thus probably, laying dry from six to eight thousand acres of land, that would more than repay the expense, and might possibly enable a trackway to be made through the lake.

These details have been given to show that a general plan of improvement of this important navigation had been carried out at an early date, although in an imperfect manner, but affording valuable examples whereby to profit in subsequent efforts, by the adoption, amendment, or avoidance of what had been already done.

Neither the trackways nor the departure from the line of the Jamestown Canal were adopted, as recommended by the fore-

going Reports, but between the years 1800 and 1812 the Directors-General expended £7,168 on the Upper Shannon, in repairing the locks, canals, and other works originally constructed on the navigation from Lanesborough to Jamestown, a distance of about twenty-six miles, together with a sum of £23,000 in making the Lough Allen Canal, extending three and a-half miles from the lough to Battle bridge, where it joins the Shannon; some minor works of general repairs were included in this sum, laid out under the advice of Mr. John Killaly, as Directing Engineer. In addition to the above outlay, the Directors-General, between the years 1806 and 1812, gave the Grand Canal Company a sum of £54,634, for making, completing, and preserving (but without trackways), the navigation of that part of the river Shannon between the northern extremity of lough Derg and the northern extremity of the canal at Athlone, the same to have six feet depth of water at the least, at all seasons of the year, with such locks, bridges, and wharves as the Directors General should think necessary. These works were completed to the satisfaction of the authorities, but at an expense to the Grand Canal Company of upwards of £30,000 beyond the sum received. It thus appears that on the works extending from Limerick to lough Allen, the outlay commencing from 1767 amounted to £211,350, to this should be added a sum of £114,523 laid out in the previous twelve years by the Navigation Board, making in all £325,873, up to the year 1812. The expenditure at a more recent date shall be given in its proper place.

RIVER BARROW NAVIGATION.

The river forms the course of this navigation, except in a few instances where short deviations were made. It extends from Athy, in the county of Kildare, to the tide water below

the rocks called the Scars, at Saint Mullins, in the county of Carlow, a distance of thirty-four miles, nearly five miles of which are lateral cuts. The works were commenced in 1759, according to the designs of Mr. Thomas Omer, who proposed to make them suitable for vessels of seventy tons at all seasons, the river in its then state not having been navigable at certain times of the year, by vessels carrying more than two or three tons. Seven locks, and the cuts leading to and from them, had been completed up to 1790, under the immediate inspection of Mr. John Semple, as Deputy Engineer. In the above-mentioned year, £22,500 having been previously spent under the Navigation Board, the Company was incorporated, and Mr. William Chapman was appointed to direct the works.

The proposal made by the Company to Parliament, was to render the river navigable for boats of fifteen tons in summer, and thirty tons in winter, with towing-paths for the whole length, and to expend for that purpose £40,000 of their own money, on receiving £20,000 from the public purse; but whatever success might have attended the first proposal, it was only partially proceeded with, for during the progress of the works the Company were induced to enlarge their project, for the purpose of enabling boats from Youghal and Dungarvan to pass through the river Barrow and Grand Canal to Dublin, without transhipping, and also to take in coal vessels from British ports; with that view twenty-four new locks were designed, 80 feet long, and 16 feet wide, with 5 feet water on the sills, to admit boats of eighty tons burthen; of these ten were built, and four of the original locks, of various sizes and of bad construction, were taken down and reconstructed on the modified plan; however, on the withdrawing of the canal bounties on produce carried to Dublin, the progress of the enlarged scheme was stopped, but only for a time, no importance having been apparently attached to the fact that the locks of the Grand Canal, which are not uniform in size, are in no

instance more than 70 feet in length, so that Dublin could not be reached by eighty-ton boats without transhipping.

After having expended on the several works £62,881, including the grant of £20,000, the navigation being still incomplete on the enlarged scale proposed, the Company applied for aid to the Directors-General, who agreed to give them £20,000, on condition of their reducing the tolls, and to give a further sum of £27,500, a moiety of £55,000, the estimated cost of completing the navigation, with the necessary locks and lateral cuts, weirs, towing-paths, &c., on the enlarged scale before specified. Those several amounts, together with a sum of £11,620, the half of which was likewise contributed by the Directors-General, had been expended on the works up to February, 1812, when a survey was made of their then state, and an estimate of the cost of completion prepared, amounting to £66,000.

The outlay from 1803 to 1812, including £78,891 granted by the Directors-General, was £149,501, if to this we add the sum of £23,500 expended by the Board of Navigation previous to the incorporation of the Company, and the sum of 66,000, the amount of the estimate to finish, made in 1812, we shall get a total of £239,001, equal to £7,029 8s. 9d. per mile, at a rate of lockage in that distance of only 5 feet per mile; a considerable portion of which would be absorbed in the declination sufficient to give impetus to the discharge of the waters of the river, and of its tributaries.

The profits in 1812, according to the report submitted to Parliament, were £2,589, or £76 per mile per annum, not including interest on capital subscribed by individuals, or on grants obtained from the Government; but had the peculiarly favourable lie of the country, for a canal the whole way, been taken advantage of, the proprietors could not have failed to obtain a far different result, as well by the economy of construction and maintenance as by the general improvement of

the surrounding districts, seeing that the Barrow navigation passes through a country of great natural fertility and high cultivation; that it meets at its outfall the rivers Nore and Suir, by which it communicates with the ports of New Ross and Waterford, and that the towns of Carrick-on-Suir, Clonmel, Ennisteague, and Thomastown, are also accessible to it from one extremity, while the port of Dublin is open to its craft at the other; time alone having been necessary for the development of highly remunerative traffic on a line so favourably circumstanced, if cheaply and judiciously constructed.

Boats can not load more than two-thirds of their tonnage in summer.

THE RIVER BOYNE NAVIGATION.

This navigation extends from Drogheda to near Navan, a distance of fifteen and a half miles, and from Drogheda to the sea, four and a half miles. The rise from the tide water to the eighteenth lock is 91 feet 9 inches, being a rate of lockage of 5 feet 10 inches per mile. The undertaking was commenced in 1759, under the direction of The Engineer of that day, Mr. Thomas Omer, and was made navigable for nine miles, as far as Slane. There were also several other works executed in the extension to Trim, which were, however, allowed to fall into ruin. Upon the whole of these a sum of £75,000 of public money was expended up to the year 1789, when the River Boyne Company was incorporated, and the navigation was carried to Navan, under the direction of Mr. Daniel Moncks as Engineer. The bed of the river is for the most part navigable from Drogheda to Stackallen, a distance of 12 miles, the remainder from thence to Navan is a still-water navigation, running parallel with the river by which it is supplied at Navan. The continuation of the line to Trim, Kells,

and Athboy, a level of upwards of 22 miles of canal without a lock was again commenced by Mr. Moncks, and again abandoned from want of funds. The intention having been to proceed from Trim to Dublin, and from the same point, on the other hand, by Kells, Athboy, Virginia, and so on to lough Neagh.

The locks vary in their lengths from 80 to 104 feet, by 15 feet wide, and the breadths of the lateral cuts are as variable as the locks are in their lengths, being from 16 to 25 feet at bottom, and from 30 to 49 feet at top, having from 4 feet to 5 feet 6 inches depth of water, these discrepancies having arisen by cutting through rock in some places, and in others by embankments made in the river. The cost of the fifteen and a half miles of navigation, from the date of incorporation, independently of the before-mentioned large amount expended up to 1759, was £115,677 11s. 5d., of which £85,800 was contributed by the Government. The produce of the tolls has been at no time adequate to the cost of maintenance and establishment.

THE GRAND CANAL.

This canal, including the Liffey line and the branches to Athy, Miltown, Blackwood (leading to the reservoir), Ballyteague, and Edenderry, may be taken at one hundred Irish miles in length. The rise from its communication with the Liffey, near Ringsend, to the summit is 278 feet, the fall from thence to the Barrow, at Athy, is 97 feet, and to the Shannon, near Banagher, 162 feet, making of total rise and fall 537 feet, which divided by the length will give $5\frac{1}{3}$ feet per mile for its lockage.

The works were commenced in 1755, under the direction of Mr. Thomas Omer as Engineer. It ascends seventeen miles,

by four double, and fourteen single locks, to the summit level, from whence, at a distance of twenty-one and a-half Irish miles from Dublin, it divides into two branches; descending by one 103 feet in twenty-two and a-quarter miles to the Barrow, at Athy, and through two double and nine single locks, with one ascending single lock of 8 feet 6 inches at Monasterevan; by the other descending 163 feet 11 inches in forty-one miles to the Shannon, through one double and seventeen single locks.

Twelve miles in length, commencing two miles from Dublin, were partly executed, and locks built for flat-bottomed barges 175 tons burthen, to be navigated by ten men and six horses, after the Dutch fashion, and calculated to pass from the city to the Shannon in eight days; the locks were 136 feet long between the gates, the upper gates six feet high, and the lower 19 feet, the breadth of the canal at water surface 32 feet, with lye-bys at such distances as to be within sight from one to the other. Mr. Omer, in his examination before a Committee of the House of Commons in 1761, stated that as far as he had gone he was within the estimate, except in the cost of experiments made to ascertain with certainty the practicability of the line, and that he was willing to contract for the finishing of the whole. The cost of these experiments and surveys in which Omer and his son, and Mr. Cooley (the designer of the wings of the Four Courts), were engaged, amounted to £48,106 4s. 9d., as appeared by the evidence of the Accountant of the Navigation Board, before a Committee of the House of Commons.

In 1763 Mr. Omer reported that four locks, several bridges, tunnels, and lock-houses had been built, the excavation completed, except in the deep rock cuttings, and that he had opened ten miles through the bog of Allen.

Doubts having arisen as to the practicability of making the canal through the bog, which had subsided in some places 30

feet, and it having been reported that there were capital errors in the levels, the works were stopped, and Major Vallancey and Mr. Trail were called on to examine and report as to what was proper to be done, the latter at the instance of the Corporation of Dublin, who had a considerable interest in the undertaking, and had agreed with the Company for the supply of the city with water. These Engineers differed widely in almost every part of their respective surveys and reports, and as observed by Philips, in his History of Inland Navigation, Trail assigned good reasons for his opinions; of this, however, there is no opportunity of judging, neither of the documents referred to being forthcoming, but Mr. Trail's Report to a Committee of the House of Commons in 1769 is still extant, in which he states that he had carefully surveyed the line proposed and partly executed, from the city of Dublin to the Blackwood river, a distance of twenty-one miles, presenting the greatest difficulties of the whole line, and that he had no doubt, from what he had seen, of the practicability of making a navigable canal for vessels of 170 tons burthen to the Bog of Allen, and from thence to the river Shannon; and as to the mistakes in the levels of the locks and other works, to which his attention had been drawn, he was of opinion they would, in a great measure, turn out to the advantage of the works, which could be finished for a sum of £34,513, as far as the Blackwood river in the bog of Allen.

On the incorporation of the Company in 1772, the works were modified, and the locks made for vessels of 40 tons burthen, under the direction of Mr. Trail, who for a considerable time kept the execution in his own hands, without any contract having been entered into, he receiving 5 per cent. on the expenditure, a mode of proceeding which turned out so unsatisfactory that the original capital was expended before the canal was made navigable to the point of partition near Robertstown, from which it was considered advisable to make

the off branch in the first instance to the Barrow, as being the district from whence a return was soonest to be expected. With the view to economy, the Company entered into a contract with Mr. Trail for the completion, by him, of the canal between Dublin and Sallins, the direction of the other works being still in his hands as Engineer. Upon the termination of the period allowed for the completion of the contract entered into with him, it was found that the banks had not been raised to a sufficient height or breadth, and that the masonry had been very badly executed. Mr. Trail (who was afterwards knighted in connexion with the Corporation of Dublin), was dismissed, and General Tarrant was appointed in his place. The sides of the locks built by Sir John Trail, under his contract, twelve in number, fell in on the water being suddenly let off, in order to test them. The opening of the canal to Sallins was by that means delayed for three years, and a very large sum of money lost to the Company.

In 1773 Smeaton having been called on, made a personal inspection of the line, and on that occasion introduced his pupil, William Jessop, to make surveys in conjunction with Trail, in order to ascertain whether a permanent canal could be made through the bog of Allen, and to lay out the best course for making junctions with the Barrow and the Shannon, from the point of partition near Robertstown. Smeaton having made a careful inspection, and taken more than a year to consider the subject, gave his opinion in detail, as recorded in the second volume of his Reports, not unfavourably to passing through the bog, where the ground, as he states in this case, could be selected, and deep cutting and banking avoided—an expectation which was far from being realized.

Under General Tarrant's direction the large locks occupying the sites of the 9th, 10th, 11th, and 12th, were taken down, and others substituted throughout, to admit boats of sixty tons burthen, and the canal was widened to 42 feet

breadth at water surface, and 18 feet bottom. On that scale the navigation was carried by that Engineer to Tullamore, in the King's County, in the year 1800, and from thence to the junction with the Shannon, within one mile of Banagher, was completed in the year 1806, by Mr. John Killaly.

Jessop, in conjunction with William Chapman, laid out the line between Robertstown and Tullamore about the year 1785, but its completion was postponed, owing to the company having directed their means to what was considered a more important object, namely, the construction of the Ringsend docks, and the canal of communication, both of which were planned by Jessop, and approved of by Chapman. The dock was commenced in 1791; it occupies an area of 25 statute acres, has 16 feet depth of water, and communicates with the Liffey by three parallel locks, where one would have been sufficient. There are also three excellent graving docks, of different dimensions. The cost of this work was £122,148, of which £20,000 was granted by Parliament. The semicircular canal of communication is three miles in length, and was estimated at £30,000, its actual cost, however, was £56,958, exclusive of interest of money borrowed for its construction; it enters the Grand Canal immediately below the first lock, which, with the lock next it, were built by Trail in a superior manner, under an agreement of five per cent. on the expenditure, but the cost having amounted to £5,000, the company were induced to let the remainder to him by contract as far as Sallins, with the results already described.

In 1788 it was proposed by Mr. John Brownrigg, Civil Engineer, to unite the Grand Canal with the Liffey by a descent of locks immediately from the James's-street harbour. The estimate, with graving docks for canal boats, was £22,000, and, having been revised by Mr, John Kilally, was reduced to £20,000, but this plan, which would have suited every purpose of an inland navigation company, by enabling their boats to

reach the shipping in the river, was rejected for the more magnificent plan of Jessop, whose design was intended to accommodate six hundred ships, the number of which, at any one time, has never since, probably, amounted to more than about a dozen, so true is it that facilities do not necessarily create a trade. The harbour for packet boats, and the hotel at Portobello, designed by Colbourne, were portions of the same scheme, serving, long before the time of railway competition, only as monuments of ill-considered outlay.

Brownrigg was subsequently appointed Engineer to the Directors General of Inland Navigation, and Killaly to the Grand Canal Company, both having been the first Irish Engineers employed in their own country, of whom we have any account.

The cost of construction of the Grand Canal, according to an account taken from papers on the Inland Navigation of Ireland, printed by order of the House of Commons, July 1812, amounted to £966,364, including a sum of £122,148, the cost of the docks, and deducting that amount, gives £8,442 as the rate per mile in actual expenditure on the works; according to the above statement, without any other aid from Parliament than a sum of £93,258, and not reckoning a sum of £73,646, uselessly expended previous to the incorporation of the Company, nor the large debt, amounting to not less than £116,750, created in paying dividends out of loans, in anticipation of profits, and in working the Castlecomer and Doonane Collieries at a loss, in accordance with the received opinion of the day—that it was practicable to compete in the Dublin market with English coal.

Amongst those who distinguished themselves in the promotion of the best interests of the Company, in which they were seconded with a strong patriotic feeling by the country at large, may be mentioned the names of Lord Harberton, Sir John Macartney, and Mr. Richard Griffith, who was Chair-

man of the Board of Directors, and a member of the Irish Parliament.

The following observations, made by Philips, with reference to the Grand Canal, in his work on Inland Navigation, is worthy of quotation for its appositeness. In concluding the notice of this undertaking, he observes:—"The failure of this great work, which at first might have been so easily completed at a moderate expense, may justly be attributed to the want of an accurate and well digested plan and survey, for it does not appear that there were any material difficulties in the whole line, but what might have been overcome with great ease had the work been properly conducted by an able and experienced Engineer, since neither money nor a proper attention to its being laid out judiciously was wanting, as may be seen by the '*resolves*' of the Company of Proprietors," which he subjoined, "to show how careful they were to be properly supplied in time, and prevent the work standing still for materials and utensils."

The often quoted opinion of an unprofessional English tourist, Arthur Young, to the effect that this undertaking was, from the beginning, a mere job, can not be allowed to weigh against the testimony of Philips, whose judgment has been confirmed by the facts here adduced, proving the *incompetency at least* of some of the Engineers to whom the works were at the outset intrusted.

ROYAL CANAL.

The Royal Canal extends from the river Liffey, at Dublin, to the Shannon, at Tarmonbarry, a distance of seventy-two Irish miles; it has its summit at an elevation of 322 feet above the former, and 191 feet above the latter, its rate of lockage being 7⅛ feet per mile. The Company of undertakers, with a capital of £20,000, was incorporated in 1789, and Mr.

Richard Evans was appointed their Engineer. The works having been carried out as far as Newcastle, twenty-two miles from Dublin, at an expense of £315,204 of which £70,556 had been granted by Parliament; the Company, in the year 1801, represented to the Directors-General their inability to proceed unless assisted by part of the grant of £500,000 before referred to. In consequence of this application, they obtained a sum of £95,866 in consideration of their completing the Canal to Thomastown at their own expense, the cost being estimated at £63,136, and from thence, by means of the grant, to Coolnahay, a distance of forty-six miles from Dublin, with a cut from Mullingar to lough Owel, also on condition of their erecting a sea lock and turning bridge at the Liffey, making docks adjoining thereto, and finishing an aqueduct and boat harbour at the Broadstone, of which Mr. Millar was the Engineer, and in further consideration of lowering their tolls to certain specified rates. The sum granted being the cost estimated by the Company for the construction of the works above enumerated, but instead of that amount, together with the sum of £63,136 before mentioned, being sufficient for the proposed undertakings, the expenditure in completing them amounted to £304,920, as proved before the Directors-General, and exceeding the estimates by £145,000, while the income arising from the low scale of tolls on which they were dependent to pay the interest on their debt, and finally to liquidate it, did not amount to more than 4½ per cent. on the sum granted.

The canal having been carried to Coolnahay, within twenty-five miles of the Shannon, it appears that in December, 1810, the debt of the Company amounted to £862,000, the interest and annuities to £49,824, two years of which were then in arrear, and their permanent expenditure, including all charges, exceeded their revenue by £45,693. To get out of this

difficulty a new Company was formed in 1812, leaving nothing to the original proprietors, but hopeful calculations which were never realized. The line was completed from Coolnahay to the Shannon, in the year 1817, at the public expense for a sum of £200,000, making in all £1,421,954, or £19,749 per mile, the cost to the two proprietors and to the nation. The rate of profit for many years after the completion, may be taken averagely at £120 per mile, per annum, or $\frac{5}{3}$ per cent. on the capital expended; a result not to be wondered at, seeing that at 35 miles distance from Dublin,—after having overcome 322 feet of lockage and other works of great difficulty, such as the excavation through the quarries of Carpenterstown, the embankment and acqueduct across the Ryewater, which cost upwards of £30,000 and the cutting through the bog of Cappagh,—the Royal Canal is but eight miles distant from the Grand Canal, and at many intermediate places not more than four miles, so that these two great canals for half their length westward are performing little more than the work of one, and hence the unproductiveness of both; whereas had the western branch of the Grand Canal entered the Shannon at Athlone, equidistant with Banagher from Tullamore, it would have commanded the trade of the middle, lower, and upper Shannon, and thus have rendered the subsequent project of the Royal Canal obviously hopeless, by taking a great portion of its expected income.

The Grand Canal Company opposed this line with all the influence they were able to bring to bear at the many opportunities which occurred during its faltering progress, but in vain, and thus these two great undertakings have remained to our day, as monuments of unsuccessful enterprise, rather than as beacons to warn their successors; for on the same ground we see the same error committed, with less injurious, but still serious ill consequences, by the two great Railway Companies; as if the *genius loci* still exercised a malign

influence, and that needless sacrifices must continue to be inconsiderately made; and now that the two canals have ceased to be a necessity for transit, and must be looked on as principally useful in supplying the city with water, they are, by a vicissitude of circumstances, about to be abandoned, and a new source adopted, involving great difficulty and expense; upon what matured consideration of so important a matter, I have not, as yet, had an opportunity of judging; but, if time permit, I shall return to this subject, as one which should not be passed over before concluding this paper.

There is throughout the whole of the navigations here described, not only an entire want of uniformity in the size of the locks of the same line, but, as might thence be expected, between locks of different lines, though having a means of connexion; as for instance, the Royal Canal boats cannot navigate the Grand Canal, nor those of the latter the Royal Canal, nor could either, from their construction, navigate the Shannon; so that all goods forwarded by either Canal, from Dublin to Limerick, and *vice versa*, and to Jamestown, and the Arigna district, in the other direction, should be transhipped into Shannon built boats, where the Canals join that river; or be transported by a class of vessels of inferior tonnage, which was the practice adopted by traders on both Canals previous to the introduction of steam tugs. The locks of the Barrow as compared with those of the Grand Canal, and the different portions of the inland communication between Newry and Belfast, present the same anomalies. Nor can England boast of exemption in this respect, for whether we look to the navigation of the Thames, the Severn, the Mersey, or the Humber, we find similar incongruities pervading the lines of canal and their ramifications, by which these great commercial rivers are united; as for instance, the river Avon, which entering the Severn at Kingsroad, is navigated by vessels of forty to fifty tons burthen,

and fourteen feet on the beam, to Bath, and onwards by the Kenneth and Avon Canal to Leamington, where it unites with the Wilts and Berks Canal, which can only be navigated by boats of twenty to twenty-five tons burthen, and but seven feet on the beam. This canal is about fifty-two miles in length, and falls into the Thames at Abington. The junction of the Severn with the Mersey by the Elsemere and Chester Canals, is similarly defective, and the junction of the latter river with the Humber, by the Duke of Bridgewater's Canal, the Grand Trunk Canal, and the river Trent navigation, are in a like predicament. Nor were the English canals, either as to cost of construction or management of the affairs of the companies, in a much better position generally, than those of Ireland, except in situations where the peculiar advantages of mineral traffic compensated for the prevalent errors of the day, and, consequently, a large proportion of them were attended with ill success in a commercial point of view, as was amply testified by the low market value of the shares, long before the depression caused by railway competition. It would be here out of place, to enumerate the many instances of unfavourable results, but for example sake, and similarity to what took place amongst ourselves, the Clyde and Forth Canal, commenced by Smeaton and finished by Whitworth, may be mentioned; of it Philips observes that, "it was a series of blunders and unnecessary expense, in which the public spirited proprietors were equally involved, with those whose selfish views had been so very detrimental throughout;" and Mr. Thomas Gray, in his work advocating the Railway System in 1825, says of the Caledonian Canal, which was not excavated within six feet of its specified depth, that "the waste of public money had been quite as great upon it, as on those public works in Ireland, of which so much has been said, although there has been less jobbing and abuse in the outlay of the money."

Up to the year 1755, the improvement of the natural beds of rivers was the only inland mode of navigation occupying public attention in England; but in that year the proprietors of the Sankey Navigation in Lancashire (who had obtained an Act for making that river navigable from the Mersey to near St. Helen's) determined to make a separate cut, which was effected in 1760; and, in the same year, the conversion of the Worsley Brook scheme, by James Brindley, into the famed Bridgewater Canal, was attended with so much success, that enterprises of that description occupied a large share of public attention until the introduction of railways in 1829, at which time 2,471 miles of still water navigation had been brought into operation in a period of 70 years, while not more than 400 miles existed in Ireland, where the first effort had been made, in 1755, in the commencement of the Grand Canal.

To come to works of the same description, but of a more modern date. The extension of the Royal Canal from Coolnahay to Tarmonbarry, on the Shannon, 32 miles in length, was commenced in 1814, and completed at the latter end of 1817, at a cost of £6,280 per mile, towards which Parliament granted a sum of £200,000. There are 21 locks, 47 bridges, and a large aqueduct over the river Inny.

The rate of wages, owing to the war prices of food, was then twice what it was in 1830, when Mr. Mullins stated in his evidence before a Committee of the House of Commons in that year, on the condition of the poor in Ireland, that the works could have been then executed at half the cost, owing to the fall in wages—namely, from 10s. or 12s. to 5s. or 6s. per week, for labourers. Timber, which, in 1830, could be had for £4 15s., had risen during the war to £18, per ton; and many other articles of general consumption in a similar proportion.

THE BALLINASLOE CANAL.

This undertaking, extending 15 statute miles, from the Shannon to Ballinasloe, was commenced in 1825, and opened in 1830, at a cost of £3,226 per mile. Its course lay through flow or soft bog, of what might be considered the most difficult kind to make a canal through, averaging from 26 feet to 46 feet in depth, and bounded by large rivers, the Shannon and the Suck; but, by a judicious mode of drainage, and avoiding the dictum of Smeaton, "not to go deep into it," the work was perfected in a cheap and permanent manner. The bog subsided fully 20 feet, on an average; in many places 25 feet, and in some few places, where the bog was very soft, to the actual level of bottom. The particulars of the method adopted are given in detail in the 4th Vol. of the *Transactions of the Institution*, in connection with the paper on the origin and reclamation of peat-bog.

That portion of the Grand Canal which passes through the town of Edenderry, in the King's County, furnishes a striking instance of the ill consequences of not attending to deep drainage, for that which was expected to be an unusually cheap reach of canal in shallow cutting, ended—after several years of unremitting labour, and enormous expense,—in the formation of a bank on either side 45 feet in height, for a distance of 80 perches; so that the canal, with the carrying up of its sides and bottom to the required level, containing 6 feet of water, was in the centre of a high artificial embankment, having a base of fully 400 feet. Indeed, the difficulties were so great, that it was more than once contemplated to abandon the line, and make a new cut.

THE ULSTER CANAL.

This canal connects lough Neagh and lough Erne. It commences in the county of Armagh, near Charlemont, on

the river Blackwater, which is navigable for a distance of 11 miles up to that point, and enters the south-eastern extremity of upper lough Erne, at Edergul, in the county of Fermanagh, winding, in its course, along the fertile valleys of the Blackwater and Finn rivers, and passing the towns of Benburb, Caledon, Middleton, Monaghan, and Clones. The length of the canal is 48 miles. There are 26 single locks, each 56 feet long in the chamber, 12 feet wide, and about 8½ feet rise. Nineteen of these locks are on the eastern or lough Neagh side of the summit, and the remainder on the western side, the difference between the levels of the loughs being about 103 feet. The intended depth of water on the lock sills was 5½ feet.

Although the advantages of this canal must have been obvious at an early date, as an important link in the inland navigation of the country, it does not appear that any practical measures were adopted to carry out such a project, until towards the close of the first quarter of the present century, when Mr. John Killaly made the necessary surveys, and prepared plans and estimates, upon which an application was made to Parliament, in the year 1825, and an Act obtained, namely "The 6th Geo. IV., cap. 193," incorporating the Company.

The difficulty of raising the amount of the estimate, £160,000, equal to £3,478 per mile, gave rise to great delay in commencing the works, and the death of Mr. Killaly, in 1832, led to the seeking of other professional advice, when Mr. Thomas Telford and Sir William Cubit were called in. Under their direction, the works—previously designed on a scale corresponding with the canals already in connexion with lough Neagh and the river Shannon—were modified, and the width and length of the locks reduced, so that the trade boats commonly used in those navigations cannot pass; and thus, that which was intended to diminish the outlay, has proved to

be very injurious to the prosperity of the undertaking, as, indeed, ought to have been anticipated, for no considerations of economy could have justified, on ordinarily intelligible principles, such modifications of a canal so circumstanced, in excluding boats entering lough Neagh from other quarters.

The summit level is supplied near the town of Monaghan by the Quigg-lough reservoir, which is a natural lake, rendered capable, by embankments, of ponding up about 14½ feet depth of water, to be delivered into the canal by a regulating sluice and feeder-channel; but although this reservoir receives the surplus water from the river Blackwater at Ballinode, when the mills in the neighbourhood do not require it, the supply to the canal is far from being sufficient; and the consequence is, that during at least three months of the dry season of each year, the summit level is impassible for trade boats. In Mr. Killaly's design, the section of the canal was calculated to contain three feet in depth of water beyond the standard navigable height, being intended as a reservoir to draw upon when circumstances would require.

The Company, notwithstanding the sacrifices made of efficiency to economy, had to contend with the usual financial difficulties of such projects in this country, and having been finally unable to raise the necessary funds, by subscription, to complete the works, they were obliged to have recourse to amendments of their acts, to borrow money for that purpose from the Loan Commissioners, in whose hands the navigation is now vested to repay the debt, the Company having failed to meet their engagements

By the Act of Incorporation, the time of completion was limited to July, 1829. By the 9th Geo. IV., c. 96, it was extended to the 20th June, 1833; and by the 1st and 2nd Wm. IV., there was a further extension to the 24th June, 1837.

Since the canal came under the control of the Loan Com-

missioners, it has been let on lease at an annual rent, and is at present held by the Dundalk Steam Navigation Company, but owing to the uniform deficiency of water, at certain seasons, the peculiar scale of the works, and railway competition, the traffic is at present very small indeed; if, however, the water supply were improved—the works put into an efficient state of repair, and the carrying trade conducted with care and regularity, there is no reason to doubt that a sufficient return would be realized to meet all current charges and leave a fair profit on the expenditure required for improvements and repairs.

Having brought the narrative down to our own time—in giving an outline of the history of the canals which supplied the first great schools of practical engineering in this country, as well as in England—I trust that it may not be considered irrelevant to state, that one of our own late Vice-Presidents, Mr. Mullins, who was an Assistant Engineer to Mr. Evans in the execution of the Royal Canal, having found the field preoccupied, almost to the exclusion of Irishmen, looked out for a combination to enable him to embark extensively in the execution of public works, and in the early part of the present century commenced with his partners, Messrs. Henry and M'Mahon, a career which, associated with engineering, will lose nothing by comparison with the most successful period of the profession in this or possibly in any other country.

Mr. M'Mahon, on the termination of the partnership, became Engineer to the Drainage Department of the Board of Works in the year 1843, and continued to fulfil the duties of that office during the most active period of their extensive operations. The drainages of lough Neagh, lough Corrib, and the upper Brosna river were the principal works of which he gave plans and specifications.

HOWTH HARBOUR.

THE various plans proposed for a harbour in this locality have been already briefly referred to in treating of that of Dublin; but nothing was done until the year 1807, when the present harbour was commenced under the direction of Mr. Rennie. The works were sufficiently advanced in the year 1819 to enable the Holyhead packets to sail from it instead of the Pigeon-house harbour, and the whole was completed in 1825, at an expense, including the removal of rocks, for the sum of £346,607, granted by Parliament.

The harbour is formed by two piers running out from the land, opposite to the town, at a distance of 2,000 feet from each other, and approaching so as to render the space within close, with an entrance 350 feet in width, guarded by jetties to prevent disturbance within. The eastern pier is formed in three kants bearing in northerly and north-westerly directions, respectively, making 2,450 feet in length. The west pier is carried in a north-easterly direction, and is 1,900 feet in length. The roadways of both are 42 feet in width, and the parapet of the eastern pier 14 feet above high water mark. The space enclosed is upwards of 50 acres, the half of which is left dry at low water of spring-tides, when the greatest depth is 11 feet.

The piers were formed of large blocks of rubble stone, promiscuously thrown in, and the slope formed at the back by the action of the sea, was carefully paved with large blocks laid in cement, being the first instance in these countries of a deviation from the horizontal wall in such a situation. The inner faces of the piers are of masonry in regular courses, the batter being one-fourth of the height. The pier-heads were built in the year 1812, with the diving-bell which had been previously rendered perfectly effective by Mr. Rennie in the construction of Ramsgate harbour.

It is not unworthy of record that the first attempt to descend

in a diving bell in the vicinity of Dublin was about the year 1780, by Mr. Spalding, who had previously made several successful experiments in other places. He twice descended to the Kish Bank, at the entrance of Dublin Bay, in a bell of Halley's construction, to view the wreck of the Imperial Indiaman; he was accompanied by an assistant, and returned in safety. In June 1783 they went down a third time, and remained one hour under water; two barrels of air were sent down to them, and no apprehensions were entertained for their security. After some time, however, the signals from below were not repeated as usual; the bell was drawn up, and the unfortunate experimenter and his companion were found dead. The next attempt was made in 1799, a brig having foundered between Dunleary and Howth, Mr. Healy, in concert with Captain Lonsdale, proposed raising her by means of a bell supplied with air, on Smeaton's principle. On the deck of a ship moored above was lashed an air pump, to this was connected five fathoms of an iron tube, and an equal length of leather, which turned into the bell; by these means a constant stream was propelled down. In the summer of 1802 Mr. Healy made the experiment, and descended on two different days. On the first he remained down half an hour, and on the second one hour and some minutes, in seven fathoms water. The scheme, however, of raising the brig was abandoned, in consequence of the vessel above, breaking from her moorings.

The diving bells employed at Howth in constructing the pier were formed of cast iron, of the same shape and materials as those employed by Smeaton, and were supplied with air from above by forcing pumps on his principle, with the most complete success; the workmen remaining sometimes four hours under water, and many persons, from motives of science or curiosity, occasionally accompanying them; the contrivance, owing to its novelty, being a subject of much general interest.

The mails were carried in 13 hours on an average from Howth to Holyhead, and from thence in 32 hours to London; but since Kingstown harbour was constructed, Howth has ceased to be anything but a fishing station, and is not only being partially silted up, but encumbered with the debris of the piers, there being little expenditure allowed by the authorities for the maintenance of the works, which are certainly most useful in giving protection to boats employed in the fisheries.

It has been a subject of frequent observation, in which Sir John Rennie has joined, that the placing of the harbour mouth to the eastward of its present site would be a great improvement, but the idea of making Ireland's Eye a breakwater to the entrance—the practical effect of which was to increase the run of the sea in easterly winds—was the cause of the adoption of the position for which Mr. Rennie was not answerable as he was not authorised to do more than to modify the plans prepared by Major Taylor, and approved of by the authorities who had selected the site.

The average time of passage of packets in 1818 was 13 hours from Howth to Holyhead, and from thence to London, 48 hours. Two steam packets, built by Manby, with oscillating engines, made several trips across from Howth to Holyhead in the Summer of 1823, but they received so much damage in the winter that they were obliged to be layed up.

KINGSTOWN HARBOUR.

Old Dunleary harbour (referred to in the first portion of our narrative, in connexion with the Bay of Dublin) having been found inadequate as an asylum for the increasing shipping trade of the port of Dublin, numerous petitions on the subject were presented from time to time without effect, until 1809, when the matter was warmly taken up by the Duke of Richmond, then Lord Lieutenant, by whose influence, backed

by local representations, an Act of Parliament was passed in July 1815, for a refuge harbour, and five commissioners were appointed, under whose directions surveys were made, and it having been ascertained that the coast about Sandycove had a rocky bottom, unfit for anchorage, a pier was decided on, to be carried out at right angles from the shore, in the line of separation of the rocky and sandy bottoms, with a view to protect, in good anchorage ground, against winds from northerly and easterly directions, which the pier, by its kants, was calculated to accomplish—being the present eastern pier—estimated at £505,000. Certain port duties, estimated to amount to £17,000 a-year, were levied by an act of 1816, to defray the expenses of construction, and the first stone was laid in May 1817, by the then Lord Lieutenant, the Earl of Whitworth.

Considerable progress had been made in this work, when it was believed to be desirable to form a corresponding pier on the west side, in order to give protection from winds in that direction, and to prevent the influx of sand from the bay.

The two piers, consisting each of four kants, forming the harbour, are carried out at right angles to the shore, at a distance next the land of 3,700 feet from each other. The western pier was intended to be 5,360 feet in length, and the eastern pier 4,300, the outer arms converging towards each other, intended to leave an entrance of 450 feet in width, bearing N.E., with jetties projecting from the internal faces, near the heads, to prevent the inrun of the sea.

Sir John Rennie, in his history of harbours, states that the works continued under the direction of his father until his decease in October, 1821, and that they were subsequently carried on by himself, in conjunction with the Resident Engineer, Mr. John Aird, on the original plan, as far as the last arm, until 1836, when questions arose as to the best mode of finishing the entrance. In order to decide that point

the most eminent Engineers and naval men were consulted by the Government, amongst whom may be mentioned, Messrs. Walker, Cubit, and Admiral Warren. The result of their investigations was that the Commissioners of Public Works, into whose hands the management of the harbour had passed, decided on leaving the entrance 770 feet in width, and to terminate the piers with circular heads of hewn-stone masonry, in a depth of 26 feet at low water of spring tides.

The experience of many years has not settled the question as to the propriety of altering the original plan, or set at rest a belief of the necessity for further protection of the entrance, for the agitation within the harbour has been found to be very great in gales from a north-easterly direction. Sir William Cubit, on being called on in 1836, recommended the entrance to be 700 feet in width, but having at the same time seen the necessity for protection, he proposed a detached breakwater, which, however, was not adopted, as it would have created a run into the harbour, and might have given rise to the formation of a sand bank. More recently, on the occasion of the construction of the Packet Pier in 1855 for the accommodation of a larger class of proposed vessels, Mr. Rendal having been consulted, recommended a return to the late Mr. Rennie's views, so far as was consistent with the piers as constructed; with that view he proposed to extend the west breakwater in the same direction as its last kant, for a length of 325 feet, and to run off from the inside of the head of the east breakwater in a S.W. by W. direction, a spur for a length of 200 feet. These works would have the effect of diminishing the width of the entrance from 770 feet to 450 feet, and altering its aspect from N.N.E. to N.E. by N. This plan was, however, rejected, on the Report of a Commission of Enquiry, although the evidence of Lieutenant Hutchinson, R.N., Harbour Master, who had resided 32 years on the spot, was in favour of diminishing the width of the entrance by the exten-

sion of the west breakwater, as proposed in the direction of its last kant, by which means the sea propelled by easterly gales, and turned inwards by the western pier head, would be diverted outwards on the back of the slope, there to exhaust its force, instead of creating disturbance and danger within. The advantage of steam-power, not contemplated by Mr. Rennie when he designed the harbour, was, as far as his authority was concerned, a strong argument in favour of diminishing the width of the entrance, on account of the greater facilities subsequently afforded for entrance and departure.

The piers were constructed of rubble stone, of large and small dimensions, thrown in promiscuously, as they turned out from the quarries of Glasthule and Dalkey: the stone suited for ashlar work being reserved. The inner slope is 1 to 1, and the outer slope or glacis 5½ to 1, at which gradient it has successfully withstood such a force of the sea as, in my opinion, would have demolished an upright wall.

The eastern pier is 4,000 feet, and the western pier 4,900 feet in length, the low-water area enclosed being 233 acres, of which 33 acres have less than fifteen feet in depth.

The old favourite project of a ship canal from Dunleary to Dublin was revived by Mr. Rennie, from the new harbour. The subject was subsequently taken up, and a survey made by Mr. Killaly, but as such matters require a long time to come to maturity in this country, a new mode of communication by railway, displaced all idea of the canal.

A pier was built in 1842, in the south-western angle of the harbour, for colliers and merchant vessels, at an expense of £30,000, and another pier for the accommodation and protection of steam packets, in the south-eastern angle, was undertaken in the year 1853, and completed at a cost of £60,000.

These internal piers were designed by Mr. Barry D. Gibbons, Harbour Engineer to the Board of Works; and that called the Traders' Wharf was built with upright casing walls, in con-

formity with the views of the then Chairman, Sir Harry D. Jones; a very short time, however, sufficed to show that such a mode of construction, on a sandy foundation, was inexpedient, as on the occurrence of a storm from the N.E., when the work was partly constructed, a trench, into which the foundation stones partly slipped, was made by the revulsion of the waves, rendering it necessary to reconstruct the wall with a broad toe course, and a proper batter.

The original intention of Rennie was to render the internal piers unnecessary, on the supposition that the two inner sides of the great breakwaters would be so sheltered as to serve for wharves.

The building of the circular heads presented considerable difficulty, particularly the western head, the position being exposed to the violence of north-easterly gales.

The circular temporary framing, containing 250 tons of timber, from which the diving bell was worked, was twice carried away by the violence of the sea, and called for the exercise of some ingenuity in the construction of a novel contrivance for building the heads; this, however, being a matter of detail, will more properly form the subject of a separate paper.

The entire cost of the works was upwards of one million, and although the amount appears large, it contrasts most favourably in that respect, as well as in permanency of execution, with structures of the same description in England.

HARBOUR OF DROGHEDA.

This is a bar harbour, formed by the estuary of the Boyne situated on the east coast, twenty-seven miles north of Dublin. The channel to the town of Drogheda, four miles and a half from the sea, is winding, and the navigation rendered still more difficult by a strong run of tide.

To remedy its defects very many unsuccessful attempts have been made, the earliest on record appears to have commenced in 1729, when by the 3 Geo. II., c. 21, the Mayor and Burgesses were constituted conservators of the port, and empowered to levy dues, to be applied to improving and cleansing the harbour. In 1759 the first Parliamentary grant was made, and in 1761 some progress appears to have taken place in the works, as we find that in the evidence given in that year before a Committee of the Irish House of Commons, with reference to what was called the Parliamentary Cut, at Drogheda, Mr. Thomas Omer stated, that it was then 166 perches in length, and would take £2,000 to complete it.

By a modification of their Acts in 1797, the Commissioners were authorised to enclose the strand, and to build quays. The remains still exist of stone longitudinal dykes and transverse jetties, constructed in 1783 by Baldwin, under the advice of Golborne of Chester, who in his report refers to the success of similar measures in the Clyde. There is also visible, at low water, the framing of the hull of a vessel, sunk with the view of closing the northern sailing course; of this Golborne observes, that the current having been suffered to make a channel between the vessel and the river bank, much of the ebb tide ran through it, to the great detriment of the navigation.

The transverse jetties or spur piers were about 2,000 feet asunder, and from 200 feet to 250 feet in length, at right angles to the banks of the river. Nothing further, worthy of particular notice, appears to have been done until 1827, when additional powers were obtained, and authority given, to raise £15,000 on the security of the harbour tolls. In consequence of this, a steam dredger—the first of the kind introduced into Ireland—was procured under the advice of Mr. Alexander Nimmo, and an embankment made from the North Crook to a point opposite the Maiden Tower, to give protection in gales from the north-east.

In 1842, an amended Act was obtained, and powers given to borrow £70,000, for the contemplated improvements. The little amelioration produced by all that had been previously done was proved by the fact, that, in that year, a vessel, built by the Drogheda Steam Company, drawing only 12 feet of water, when fully laden, was unable to take in more than a portion of her cargo at Drogheda, and the remainder at the mouth of the river, where a wharf was erected for the purpose. At that period, there were but 3 feet over the bar at low water of spring tides, which rise 12 feet.

In 1844, Sir John Macneill, having been appointed Consulting Engineer, recommended that the jetties should be removed, as they obstructed the flow of the tide, and had produced no beneficial effects on the bar, and that, with the materials of them, a breakwater should be built along the margin of the North Bull, to keep the sand from being washed in by the sea.

The Harbour Board, being in want of means to proceed, obtained a loan from the Lords of the Treasury, in 1844, and since that period the works have been under the supervision of Mr. Barry D. Gibbons, Harbour Engineer to the Board of Works, by whose direction the jetties have been removed, and the river course enclosed by walls built of dry rubble stone backed with the coarse gravel lifted by the dredger in deepening the river. The water being thus prevented overflowing the mud lands, the velocity of the ebb tide was so considerably increased as to remove many of the sand banks which had obstructed the navigation, and to bring the bottom of the channel to a more uniform level, leaving from 5 feet 8 inches to 6 feet depth at low water; but as the walls were constructed only as far as the river banks extended, and that a mile in length of the mouth of the river was exposed to the open sea, a most serious injury arose in times of storms, as, from want of some protection, immense quantities of sand were driven

into the river by E.N.E. and S.E. winds, and settling down in the channel, had to be removed at considerable expense by dredging. To remedy this evil, Mr. Gibbons had recourse to a simple and inexpensive, but effectual, plan of driving into the strand two rows of stakes or small piles, 2 feet 6 inches apart longitudinally, and 1 foot 6 inches, transversely, on each side of the river, extending as far seaward as practicable, and woven into hurdles, by interlacing them with wicker-work, a strong backing of rubble-stone being deposited to give them protection.

In the first winter after the erection of the hurdles, the sea made two breaches in them, which were repaired without delay, and subsequently the accumulation of sand became so considerable as effectually to resist the waves, which ascend and descend freely at the inclination formed, and thus prevent storms having any effect on the artificial beach. The angle made by the line of wicker-work running along the river with the line of high water on the shore, embraces more than 80 acres of the strand, and, judging from the rate at which the space is being filled by the drifting sands, it is probable that the whole will be raised above the influence of the tides before the lapse of many years, several acres of it being already from 3 feet to 8 feet above the original level of the beach, and growing bent grass where the tide flowed within the last eight years.

After the wicker-work had been completed, as far seaward as practicable, the sea walls were continued from it until they had reached within 680 yards of the bar. The effect of these operations has been, that, in the summer of the present year, a vessel, drawing 15 feet 6 inches on a 13 feet tide, crossed the bar, and reached the town, from which may be inferred the improved state of the navigation.

The dredging of the accumulated sand out of the river, usually occupying the summer months, at a cost of about

£700 a year, has not required the expenditure of more than £60 in the same period during the last seven years, giving the great additional advantage of leaving the dredger available for deepening the shoals, so that the deepest water is now to be found where the greatest impediments formerly existed. The depth of water in the river at ordinary spring tides is from 17 feet to 18 feet, with 22 feet on the bar, the depth of which has been permanently increased from 3 feet to 5 feet 6 inches. There is a difference of 4 feet 3 inches in the level of the bottom of the channel, between the town and the bar, and 3 feet 6 inches of this difference is in the last mile and quarter. The current of tide runs rapidly at about half ebb, the average velocity for the 3 miles next the harbour being one mile three-eighths, and for the remaining mile and a-half two and a-quarter miles per hour. The difference in time of high water on the bar and at Drogheda is about half an hour at spring tides. The depth in the harbour varies occasionally with the wind, a N. or N.E. wind lowering the tide from 10 inches to 15 inches, whereas a S. or S.W. wind raises it from 1 foot to 2 feet. No shifting of the bar has taken place for the last five years.

The results of the operations carried out under the direction of the Board of Works must be considered successful, so far as giving facilities for a small class of vessels, but it appears to be very questionable whether the expenditure of upwards of £1,000 a year—in cutting off, by dredging, the sharp angles of the river, as now being done, to give additional facilities in sailing round the curves of the serpentine course of the river—is judicious, seeing that the money might be better expended, as recommended by the Resident Engineer (Mr. Donor), in making a new channel on the south side of the river, 434 perches in length, commencing between the White and Black Towers at Branagan's Point, from thence passing through the slob land at Mornington, and entering the river again on the

N.W. side of the Maiden Tower. This would do away with the zigzag portion of the channel, and give a direct run to the bar. The mouth of the river being well sheltered by the sea walls, and being 800 feet wide, would afford perfect safety to vessels running in there in bad weather.

As a very large proportion of the excavation for the new cut would be free from water, it could be executed on reasonable terms, and the quantity of valuable slob land reclaimed, upwards of 900 acres, if sold, would nearly pay the cost of construction, estimated at £47,000. This is believed to be the only mode of improvement by which the port can be made to admit a large class of vessels, and the benefit obtained of the utmost results from the large expenditure already made.

There are four plans of the port extant; one by Sherrard, made about 1786; that by Nimmo in 1826, accompanying his report; that by Bald in 1837, and an Admiralty Survey of the Bay of Drogheda, and of the soundings of the coast, made by Captain Frazer, R.N., in 1839.

ARDGLASS HARBOUR.

The bay of this name is situated on a prominent point of the eastern coast, three miles north of the dangerous receding portion of it, known as Dundrum Bay. There being no other harbour accessible at all times of tide, in a northerly direction, nearer than Belfast, 45 miles distant, and Kingstown on the south, 61 miles; much attention has been consequently directed to this locality, possessing some natural advantages of a limited nature, but capable of being extended by a judicious and sufficient outlay.

In order to give protection to the fishing boats belonging to the place, as well as to those frequenting the Irish Sea from

St. Ives and the Isle of Man, which lies opposite, at a distance of 30 miles, the proprietor of Ardglass, Mr. Ogilvie (having obtained an Act of Parliament in 1812 to enable him to levy dues, and for the appointment of Harbour Commissioners) commenced a pier and sea pavement based upon an inner ledge of rocks, which formed the natural beaching cove of the little bay. These works were subsequently completed by his heir, Major Beauclerk. The shelter thus afforded to about half an acre was found so useful that an extension of the pier 245 feet in length into 17 feet depth, at low water, parallel to the sea aspect, and covering an additional area of an acre, was determined on by the spirited proprietor, according to the design of Sir John Rennie, adapted to afford shelter to vessels of the coasting class, in 15 feet depth of water, at an estimated cost of £22,000. Mr. Ogilvie continued to advance funds to the amount of £16,000 for which the Harbour Commissioners gave debentures to his heir, Major Beauclerk.

In 1822 Mr. Alexander Nimmo inspected the harbour and advised, in order to get rid of the great run in S.W. winds, to cut a passage across the rocky ledge separating the present from the middle harbour, as far as the opening behind Maggy's Rock, all of which is accessible at low water, and to build with this a breakwater on the outer and broader part of the ledge, behind the perch. The run, having then room to pass into the middle harbour and out at its present entrance, would be greatly diminished at the pier.

In the Spring of 1822 Sir John Rennie reported on the progress made in the construction of the pier, and estimated the amount necessary for its completion at £6,650; on this report the Harbour Commissioners applied to the Board of Works for a loan, which was granted to the above amount, and in September 1832, according to a report and estimate made by Mr. Hamilton Killaly, by order of the Board of Works a sum of £2,150 was then required for the completion of the

works. Towards the end of December of the above year the pier was closed, but by that time the funds were exhausted; the parapet, coping and pavement being in an unfinished state; the original estimate having been exceeded by the addition of 52 feet to the pier, in order to give greater tranquility and accommodation within the harbour.

The Harbour Commisioners applied for a further loan, but were refused, and the works remained unfinished, while Major Beauclerk in vain urged the Treasury either to make a loan or to place the securing of the pier in the hands of the Board of Works.

In 1837, the first year after the closing of the pier, shelter was afforded to 210 vessels, averaging 150 tons burthen, and a fleet of nearly 500 small craft landed £20,000 worth of fish, principally herrings, on the New Quay; these promising results were not, however, of long duration, for in the second year the pier became broached by an autumnal gale at S.S.E., and no timely repairs having been attempted, the circular head was undermined, and the lighthouse, which was founded upon it, and erected by the Ballast Board, fell into 20 feet of water; the materials of the pier were carried into the harbour, where they still remain visible above low water, destroying the only quay for lying alongside at low water.

Mr. Vignolles reported on this disaster in 1839, and recommended that the plan should be modified, and the works rebuilt with large blocks from the Isle of Man or Donaghadee, mixed with the stone of the locality; he was of opinion that in the construction, serious errors had been committed, amongst which the following may be enumerated:—1st. Great unnecessary expense of labour and materials on the interior faces, and in parts not exposed to the direct action and weight of the waves. 2nd. The slope of the glacis, or sea pavement, was too steep, being only 4 to 1 from the top of the bell work to the top of the parapet. The parapet was also 3 feet too low

for the run of the sea. The exterior face of the parapet should have been bonded into and formed part of the top of the glacis, and the interior face and the general body of the wall should have been strengthened with through bonds, and the foundation laid lower than it was. 3rd. The re-entering angle, formed by the junction of the circular head with the straight line of the pier, offered a vulnerable point, and it was near this angle that the first breach was made. The position of the projection of the circular head should be reversed, keeping the outer line of the pier straight, and making the re-entering angle on the inner or harbour side instead of on the outer side as constructed.

Memorials having been sent to the Lords of the Treasury in 1845, from the Chamber of Commerce at Belfast, from the bankers, merchants, and shipowners of Liverpool, from the merchants and shipowners of Whitehaven, from 1,200 shipowners, masters, and mariners who had occasionally visited the harbour of Ardglass, and the matter having been in consequence referred by the Admiralty to Captain Beechy, of H.M.S. Firefly he, by a very little effort of the pen, settled the question in the following brief communication, dated 4th May, 1845:—

"Ardglass is not, in my opinion, worth the money it would take to repair the pier, either as a harbour of refuge or a place of resort for more than one steamer in bad weather. The harbour is too confined, the water at its entrance too deep, and within too shallow for it ever to become a place of refuge with easterly gales, when alone it would be required as such.

"As a snug little cove where a steamer might pass a night, or land her passengers and be off (which I think she could do in an easterly gale), or where fishing boats might resort and lie a-ground, it is all very well, and a pier would render it more safe than it is at present; but as regards the navigation of the Irish sea, I do not think it worth the particular attention of the Government."

In 1851 Captain Denham, R.N., and Mr. Rendal were

called on for their advice. The latter recommended the restoration of the works and the construction of another pier from the rocks, on the opposite side of the bay. He observed that it is under the lee of the former pier with the debris of the new pier acting somewhat as a backwater, that upwards of one hundred and thirty vessels still take shelter, notwithstanding that the harbour light is no longer in operation to guide them up to the round of the pier-head, but merely denotes when they are right off the mouth of the bay itself, the light now exhibited being from a stable loft, which is the only means of showing the fair way direction, so that a vessel has been known to pass beyond the pier-haven upon the strand at the head of the bay. Captain Denham observes, that no stranger can avail himself of Ardglass harbour of a dark night until the light is restored, and this he recommends to be done on the extremity of the ruins of the pier, or by rearing a light tower on the foundation of the late head which bares two feet at low water of springs, and is in a fit state to receive a superstructure.

The government steamer, Comet, having been taken in a violent gale off Ardglass, in the winter of 1851, ran for this harbour and rode out the gale in safety, with the protection of the dilapidated pier. The commander, Captain Jeffries, in reporting the circumstance to the Admiralty, recommended the harbour as worthy of being rendered fit for refuge, so much required in this part of the Irish sea.

Captain Denham remarks, that the harbour has been usually considered only with the view of rendering it suitable for coasters and fishing craft, because the cost of projecting breakwaters from the head-lands, which form the mouth of the bay, in order to extend it to the capabilities of a harbour of refuge, would be an undertaking too great for private enterprize, but certainly worthy of an appropriation of national funds.

Mr. Rendal reported of the capabilities of Ardglass as a

harbour of refuge; that it would be necessary for that purpose to form break-waters from Coleman's Head on the west, and from Phœnix Point on the east, enclosing a high-water area of about 100 acres, the low-water area between the head-lands not exceeding 55 acres. The distance between the two head-lands, bearing east and west of each other from the low water, is about 1,900 feet, within which is a funnel-shaped creek about 2,400 feet in length, having 9 fathoms of water at low water of spring tides in the deepest part.

The portion of the creek forming the old harbour having 10 feet of water and upwards at low water of spring tides, would give a sheltered anchorage of 17 acres, exclusive of Castle Cove, which forms a good inner harbour for coasters and fishing craft. These seventeen acres of anchorage, for vessels drawing from 9 to 17 feet, and Castle Cove, about six acres, adapted to smaller vessels, may be sufficiently protected by the restoration of the fallen pier and lighthouse; but increased accommodation can only be advantageously procured by the proposed breakwaters; that from the west point to be 1,050 feet long, in from 3 to 9 fathoms at low water at spring tides; and that from the east side to be 650 feet long, in from 3 to 8 fathoms. Mr. Rendal's estimate for these works amounted to £240,000, including the cost of lighthouses and a breastwork or parapet for the whole length of each breakwater. The time of completion he computed at 5 years; the stone of the locality to be used up to low water, and from that level limestone or granite. For the above expenditure there would be a safe refuge-harbour of about 35 acres, having from 3 to 9 fathoms of water with excellent anchorage ground. The estimate was based on the well-known exposure of the coast and the heavy sea which the works would have to encounter.

In case it should be decided that costly works were not desirable, Mr. Rendal strongly recommended the restoration of the pier and lighthouse, washed down by the gale in the

autumn of 1838. The cost of this, with the removal of the detritus which now contracts and endangers the present harbour, he estimated at £20,000. If the breakwaters were built the expense of reconstructing the pier would be reduced £8,000, and it could then be made an inner shelter, as well as a wharf, for trading purposes.

With reference to the propriety of restoring the pier, the Commissioners of Public Works make the following observation, addressed to the Lord Lieutenant, dated 11th March, 1848:—

"This Board is fully impressed with the value of Ardglass Harbour, and still entertains the hope that means may be provided for its restoration upon a permanent footing. The cost of effecting this is quite beyond the reach of any fund at present connected with this department. It may be added that in 1840 this Board, under the sanction of the Treasury, offered to pay half the cost of restoring the harbour, provided the parties interested supplied the other half, and also undertook the maintenance of the harbour, which was declined."

Now that the railway is open from Belfast to Downpatrick, seven miles distant from Ardglass, there is reason to hope that the attention of the enterprising merchants of Belfast will be turned to this locality, offering the only harbour without a bar in a distance of upwards of 100 miles, between Kingstown and Belfast.

The remains of ancient castles crowning the heights in the neighbourhood of Ardglass, give some evidence of the importance of the place in former times.

BELFAST HARBOUR.

Belfast is situated at the western extremity of the lough of Belfast, at the confluence of the river Lagan with that estuary, called also Carrickfergus Bay. It is 102 miles north of Dublin, in the county of Antrim. The port is formed by the mouth of the river Lagan, which falls into the head of the

Belfast lough, after a course of about 36 miles, without becoming of any considerable breadth, except opposite the town, where the depth ranged from 2 to 6 feet, and below the town there is a line of mud banks, called flats, having on them 8 feet water at low springs; from these banks the channel gradually increases until it enters into a depth of from 16 to 20 feet at the lowest water, in the safe roadstead of Garmoyle; from thence, however, to Belfast, a distance of three miles, the navigation was so bad that large vessels could not reach the quays, except at high water of springs, and it was necessary to carry goods in lighters from Garmoyle Bay to Belfast.

In order to remedy this great hindrance to the trade of the place, plans were obtained in the year 1814 from several Engineers, amongst whom may be mentioned Mr. Bevan, Mr. Rhodes, and Mr. Killaly, the latter of whom was then Engineer to the Board of Customs, and who recommended the construction of a dock, and a short canal to Mile Water Reach, estimated at £122,600. The various plans were referred to Mr. Rennie, who disapproved of them, and proposed instead to make a deep water channel from the town to Garmoyle, and to provide accommodation for all classes of vessels, so that they might lie afloat in front of the quays at all times of tide, converting the river into a floating dock of 26 acres area. The communication with the roadstead of Garmoyle, he was of opinion might either be by an open deep water tidal channel, or a lock ship canal, the latter he recommended. The estimate of the whole of the works proposed by him amounted to £450,000.

A modification of this plan was also proposed by Mr. Rennie, at about half the cost of the other, but neither came within the means of the Corporation, and matters were allowed to remain in the same unsatisfactory position. Plans were furnished in 1826 by Sir John Rennie, and in 1829 by Mr.

Telford. In 1831 Messrs. Walker and Burges having been consulted, gave plans which were approved of; these consisted of an open tidal channel in a direct line from the town to what is called the seal channel, with 12 feet water at low spring tides, the bed of the river near the town to be deepened to the same extent. At the end of the channel an outer harbour was to be formed for vessels to lie afloat in, when the tide would not allow of the opening of the gates of the wet dock, to be formed in the Corporation grounds, covering a space of eleven acres, with a lock communicating with the river, 180 feet long 48 feet wide, and 12 feet deep at low water of springs. The estimated cost of these works was £180,000. Further improvements of the existing harbour, with quayage and other accommodation for steam boat traffic, was also recommended, making a total of £311,000. The objections raised to the plans of Messrs. Walker and Burges, were that the scheme of an open cut was liable to accumulation of silt from the waters of the Lagan, and that a bar would be formed at Garmoyle, but this objection not being considered well founded, an Act was obtained in June, 1837, to carry out Mr. Walker's plan, giving powers to take lands, also to increase dues, and directing the order in which any funds that might arise should be applied. The money question, however, again became an impediment, and Messrs. Halpin, Rhodes, Cubit, and Woodhouse were severally called on, and made plans, but it was not until 1839 that the new channel recommended by Mr. Walker was commenced, when a loan of £25,000 was obtained from the Board of Works, the depth having been reduced to nine feet, instead of twelve, as originally proposed. This was completed in 1841 for a sum of £42,464, the first bend of the river being thus cut off.

In 1841 the Corporation, in order to carry out the objects of their Act, applied to the Board of Works for an additional loan of £185,000, which was refused, they thereupon obtained

an Act to enable them to raise the necessary amount. The period for compulsory purchase having expired in 1843, an extension of time was granted by the Act of that year, the Corporation were also relieved from the condition of an order of works, and since that period the construction of the new quays, and the first section of the new cut, were carried on with success. The merchants interested took bonds in part payment of the site of the quays, and thus left a considerable sum for immediate outlay. At the period of the investigation of the Tidal Harbour Commissioners in 1845, nearly £200,000 had been expended, either in the construction of works, or the purchase of land.

In 1849 the lower portion of the new channel was made, at an expense of £42,791, thus cutting off the second bend; this, with the spoil bank operation, of forming out of the material an island of 17 acres, and constructing about 3,000 feet of quayage, were the only considerable works performed of the many contemplated by the numerous designs submitted; there have been, however, some timber ponds made, these, with the dredging in front of the town, and purchasing the site of the intended improvements, complete the enumeration of the results obtained by an expenditure which from 1837 to 1851 amounted to £474,073.

The special advantage claimed by Mr. Walker for his plan was that it could be carried into effect by degrees, each step or measure being complete in itself, but at the same time a part of a great connected whole; such piece-meal improvements, however, are often found to be most wasteful on account of the protraction of the execution.

In the extensive range of professional advice taken, the corporate authorities of Belfast certainly appear to have adopted the maxim that there is wisdom in multitude of counsels, but it must be admitted they have signally failed in giving it an economic practical application.

The importance of the port may be judged from the amount of its exports and imports, which were £11,571,280 for the year 1850, and the revenue of the year upwards of £27,000.

CARRICKFERGUS HARBOUR.

THE seaport of Carrickfergus is situated on the western side of the estuary or lough of Belfast, 110 miles north of Dublin, and 9 miles north-east of Belfast, whose prosperity has left little or no trade, or pecuniary means of providing accommodation for shipping at Carrickfergus.

The harbour is formed by a pier running out 460 feet in a westerly direction from the old castle, built in the time of Henry II., projecting into the sea. Within the pier the depth at high water of springs is only from 8 to 9 feet, and 6 to 7 feet at neaps, and even these depths can not be preserved without occasional removal of the silt to which the shore is subject.

Sir John Rennie having been called on in 1832 to suggest a plan for the improvement of the harbour, recommended a new one outside the present, carried to a depth of 17 feet at low water of springs, and in order to guard against the silt drifting along the shore, he proposed an open causeway pier upon arches, in a southerly direction, for a length of 850 yards. Beyond, and on each side of that causeway pier, he proposed to construct two detached breakwaters, that on the east side being 1,500 feet, and that on the west side 800 feet long, placed so as to correspond with the ebbing and flowing currents, and to give protection against easterly and westerly winds, and leaving an entrance of about 80 yards between them. The breakwaters were intended to give shelter, and the causeway pier for loading and unloading. The estimate of the plan, capable of being rendered more extensive, was

£55,000. Want of means, or of enterprise, or perhaps both combined, prevented the proposed improvement of this port, the situation of which is well suited for a coasting trade.

Carrickfergus is a fortress of a very ancient date, and early in the seventeenth century the town was the most important place of trade in Ulster, before the introduction of manufacturing industry had raised Belfast to an absorbing importance in that quarter.

BALLYCASTLE HARBOUR.

THE prevailing opinion of the practicability and benefit to be derived from supplying the capital with native coal, induced the construction of this work in connexion with the collieries in the locality, which had been worked from a very remote date, as noticed by the Rev. Dr. Hamilton, in his description of the north coast of the county Antrim.

A grant of £10,000 was made in 1737 to Hugh Boyd, Esq., of Ballycastle, in the county Antrim, to construct a harbour of certain specified dimensions, within a period of four years from its commencement, and to deliver at it, on ship board, for a term of 21 years, 20,000 tons of coals yearly on demand, at 4s. 6d. per ton.

The works were commenced early in 1738, under the direction of Mr. Steers of Liverpool, who gave the plans and specification of the work, and Mr. William Needham was employed as Executive Engineer.

The piers to enclose the harbour were founded by driving treble rows of piles in the site of each pier, for a length of 560 feet, and 32 feet in breadth, in bays of 15 feet in length, filled in with rubble. The piles were of oak, 29 feet long, and 12 inches square, procured from Neath, on the west side of the Bristol channel. Towards the end of the piers, the bottom being rock, the foundation was laid in caissons.

There was accommodation for 60 ships, of 120 tons burthen, but a great influx of sand, requiring constant dredging, showed that the site was badly chosen, and the winter storms having carried away portions of the ends of the piers, it became necessary to secure them, and with that view Mr. Christopher Myers was consulted in 1758. He built 150 feet in length of the extreme end of each pier of hewn stone raised on the old foundations, the stones were from five to ten tons weight, and from six to ten feet in length, well bedded with their heads to the sea. The construction of the harbour, for which Parliament had granted £22,800 was reported in 1762 to be complete, and that the work could not be disturbed by any force of the sea. How long that prediction held good there are no means of ascertaining, but Sir R. Griffith, in his survey of the Antrim District in 1829, states that the piers having given way the harbour had become nearly useless, having filled with sand.

The collieries were carried on with some success, but not so as to be able to compete in price with English coal in Dublin. The neighbourhood of Ballycastle had also the advantage of very productive salt works.

CORK HARBOUR.

This may more properly be described as the harbour of Cove, and from its great extent of sheltered deep water, with a good channel, offering the requisite facilities for access and departure, has not called for any engineering works for its protection. The entrance of the harbour is about two miles in length, and one mile in breadth. The harbour itself is three miles in length, and two and a half in breadth, of this there is a well protected space of two nautical miles in length, and one-third of a mile in width, with a depth of from six to fifteen fathoms

in good holding ground. It contains Spike Island and Haulbowline. On the former, Fort Westmoreland is said to command the entrance, the latter island is a victualling depôt for the navy. No part of the United Kingdom is better suited for a naval arsenal or dock yard; while Woolwich and Deptford had been condemned as long back as 1806, by the Board of Naval Revision, and all the money that has since been lavished on them has failed to remedy their defects.

The enterprise of an individual, Mr. William Brown, has supplied a want much felt, namely, graving docks; on the construction of these £150,000 have been laid out by him at Passage, up to which there are twenty feet of water at the lowest neaps. There are two graving docks, the larger has from 21 to 24 feet water on the sill, with an entrance 80 feet 6 inches wide, and length for the largest ships or steamers. Four of these can be accommodated at the same time. It can be used as a dry or floating dock, and is closed with a caisson. The Cork Steam Ship Company also, of which Mr. Pike is Managing Director, have within the last few years constructed and fitted with machinery, made upon the spot, some of the largest and finest iron screw steamers now in the channel trade.

Between the deep water at Passage and Cork, a distance of five miles, the river Lee was so tortuous and encumbered with shoals that vessels drawing more than ten feet could not reach the city at high water of springs, and until very recently vessels were obliged to unload at Passage.

From the year 1759 up to 1767 a sum of £21,500 was granted by the Irish Parliament to remedy the defects of the navigation, but from that period nothing appears to have been done until the year 1820, when an Act was passed for the improvement of the port and harbour, and Commissioners were appointed, without, however, producing any beneficial result, until 1826, when steam dredging was adopted, and by availing

themselves of the subsequent improvements in appliances of that description, the Commissioners have succeeded in making a channel throughout, from the deep water at Passage to the quays of Cork, having 21 feet at ordinary spring tides, and 17 feet at neaps.

Cork is situated at the head of the estuary of the river Lee, which dividing into two branches about a mile above the city, and uniting below it, forms several islands, constituting the principal portion of the site of the town. The arching over of the intermediate channels, in order to obtain space, as the necessities of increasing population demanded, has gradually combined the whole into one island, connected with the main land by six bridges, leading to the extensive suburbs. The bridges worthy of description shall be given under the proper head.

WEXFORD HARBOUR.

This port, situated at the entrance of the Irish channel, from its proximity to St. David's Head, South Wales, distant about 45 miles, has always been considered a desirable place for postal communication with the southern districts of England, as well as being otherwise of much commercial importance, and has, consequently engaged the attention of almost all the Engineers of eminence during the last half century, in order to solve the difficulty of providing a remedy for the shifting bar, with which the entrance is beset, and to regulate and direct the tortuous internal channels.

The harbour of Wexford is formed by the extensive estuary of the river Slaney, where it discharges itself on the east coast, about seven miles distant from the Point of Greenore, and twelve miles from the Tuskar light. The entrance into the harbour between Roslaire and Raven points is less than half a

mile in width, and from five to eight fathoms deep, shoaling again on the outside, and leaving no passage with more than eight feet depth between the extensive sand banks intercepting the sea from the harbour. These obstructions, of which the Dogger Bank is the largest, extend about three miles north, and the same distance south of the entrance, and vary from one quarter to three quarters of a mile in breadth, between high-water marks inside and outside.

In the channel within the harbour, the depth at low water is from six to nine feet. The main channel, from the Wexford bridge to the point of discharge at the fort of Roslaire, is very winding, being nearly six miles in length, while in a direct line the distance is less than four miles; there are also various other channels which join the main one.

From the quay at Wexford to Polldarrig, a distance of nine and a half miles up-stream, the depth of water is sufficient for the largest class of vessels that can enter the port. The remainder of the distance, seven miles to Enniscorthy, is so obstructed by shoals as to be navigable only for flat-bottomed boats at favourable states of tide. For the whole distance, sixteen and a half miles, from Wexford to Enniscorthy, the width is irregular, contracting suddenly and expanding into basins, the scouring power being finally so diminished that the material brought down by the stronger currents is deposited, and forms a barrier by which the present level of the river bed is maintained.

The extent of the estuary parallel with the coast north and south, is upwards of eight statute miles, and its average breadth from Wexford to the mouth of the harbour nearly three miles, giving a tidal surface of twenty-four square miles.

The catchment of the river Slaney is stated by Sir Robert Kane, in the Industrial Resources of Ireland, to be eight hundred and fifteen square miles, and the detritus carried from that great extent, together with the soil forming the natural

bed of the harbour, is alternately dislodged and deposited, until banks are formed by cross currents outside the harbour mouth, and these again are increased by sand thrown up from the sea by storms.

According to Commander Frazer's chart of 1843, the depth of water on the bar is not more than from 6 to 7 feet at low water, whilst spring tides do not rise more than 5 feet, and neap tides only from 2 to 3 feet.

Of the eighteen and a half square miles constituting the area of the harbour, fifteen and a half are mud lands, over which spring tides do not rise more than three feet, causing great obstruction to the flow of the tides in and out. The high water of neap tides covers about one-half of the mud lands, to a depth of one foot, adding but little to the power of the ebb tide, and the passing in and out of the tidal waters, in a direction almost at right angles to the main current outside, produces altogether a combination of circumstances most favourable to deposit, and therefore constitutes the difficulty of making and maintaining a good entrance to a harbour situated on a flat sandy coast, in front of an eddy tide, with not more than an average rise of four feet.

Sir John Rennie having been consulted in the year 1831, as to the best means to be adopted for remedying the defects of the harbour, was of opinion that the various currents running counter to each other, within and without the bar, should be collected together, and guided so as to act in one and the same direction, and to prolong their effect beyond the entrance; with that view he advised that no further embankments for the reclamation of land over which the tide flowed, should be permitted, without making compensation by an adequate excavation, or better still, by increasing the depth or width of the space for the reception of the tidal water. He considered that the prejudical effect of the embankment of 800 acres from the coal channel in 1816, was quite obvious, the abstraction of

the quantity of water being a great cause of the deterioration of the bar, which began to take place about that time, there having been, according to reliable authority, fourteen feet of water on it at low water, previous to that operation.

Sir William Cubit, in his Report of 1838, observed that a great deal of mud land might be enclosed by embankments, and reclaimed, possibly, with advantage, but certainly with doubtful effect as to the harbour, where the rise of tide is so small, because every cubic foot of water stopped off from the slobs would be prevented from running twice over the bar, therefore he would say that, in this case, not a single yard, capable of being covered with the high water of a neap tide, ought to be embanked off from the harbour.

Mr. Robert M'Call, C.E., in the year 1837, suggested a plan for making a new entrance to the harbour, stopping up the present entrance, and making a cut 400 feet wide, and 20 feet deep, embanked on both sides from the quays at Wexford to a point three miles south of the present entrance into the south bay, where there is deep water, by these means all the mud lands covered at low water would be enclosed.

This plan was rejected, owing to the circumstance that the proposed new cut would make such an angle with the channel which passes the quays at Wexford, that the scouring power would be turned to the opposite side of the channel, and the quays would consequently be blocked up with mud, besides there was no security that a bar would not be formed at the mouth of the new cut.

Captain Vetch, in his Report of the year 1840, while refraining from all questions about altering the entrance of the harbour, or interfering with the main channel, the effect of which he considered most difficult to anticipate, observed that the harbour being oblong in the opposite direction of the entering and retiring tide, a surface of water was admitted less useful as a scour than if the form were funnel shaped; there

being, therefore, a limit to which the admission of tidal water was desirable, he selected spaces from the north and south wings of the harbour, suitable for embankment, and recommended that every facility and assistance should be given to direct the tides up the main channel, past the quays at Wexford, through the inner harbour, and up the course of the Slaney to Enniscorthy.

Captain Frazer, Commander of H.M. Surveying vessel, "Lucifer," in his letter of June, 1845, addressed to Captain Beaufort, came to the conclusion, from his long and close observation of the tides, as well as the nature and character of the sands which sweep round the entrance to Wexford harbour, that any works thrown out from the entrance with the view to scour a more direct channel inward, would prove unavailing, and that they would only tend to remove the impediment some little distance farther out. He recommended that means should be adopted to assist in the improvement of the Hantoon natural channel, by deepening and widening it to a limited extent, by means of a steam dredger, and he did not concur in the objection that it would be filled in again by the gales from the East. He also considered there was an absolute necessity for a steam dredger, for the improvement of the internal harbour, but more particularly for the removal of Gull bar.

Mr. James B. Farrell, who was County Surveyor and Resident Engineer at Wexford, has given the result of his very careful investigation of the difficult question of improving the harbour, in an able Report, published in the Proceedings of the Tidal Harbour Commissioners in 1845. Referring to that Report, Captain Washington states, that it has established a character for the writer second to none in this country, in the theory of hydraulic engineering.

Mr. Farrell's plan was based on the principle of allowing such a large and effective influx of water to enter as would, in its return to the sea, be able to keep the entrance free from

obstructions, also directing and regulating that quantity, so that it should produce no excessive velocity, as that excess might be the cause of evils fully as injurious as those resulting from too great diminution of what is called the scouring power.

In harbours receiving the waters of large rivers, such as the Slaney, he was impressed with the belief that consistently with the principles laid down, the more gently the current of the river and ebbing tides flow to meet the ocean, the less reason there will be to apprehend the formation of bars, provided that by giving the waters a proper direction and depth, and removing all injurious obstructions, a uniform momentum is afforded, approaching as nearly as possible to that arising from the propagation of the tidal wave outside. To attain that object he made the following recommendations. The deepening and regulating the width of the river from Enniscorthy, so that there should be the same rise and fall of tide there as at Wexford. The erection of a jetty to direct the Slaney in a gentle curve round the mud bank called the Point of Park, in order to shut up the present channel of the rivers coming from Castle bridge, and to lead their waters through a new cut into the main channel, in the direction of its current of ebb, instead of being, as now, opposed to each other. Dredging away the whole of the Point of Park. Removing the bridge and causeway at Wexford, and opening the high-water channel to its original dimensions. Contracting the high water of the tidal basin below the bridge by embankments, so constructed as to collect and lead the ebb and flood by the best direction, in and out of the harbour, to and from the deep water of the north bay. Dredging the whole of the new basin to a uniform depth of eleven feet below low water of spring tides. Widening the mouth of the harbour to about three-fourths of a mile, at high water, and dredging the bottom of the additional width out into deep water. Encouraging, by piling, planting bent grass, and other means, the growth of Dogger Bank into a

permanent island. Dredging Hantoon channel, and thus obtaining the great advantage of two entrances, one from the north, the other from the south.

If these works were done he had no doubt that the result would be the reduction of high and low water at Enniscorthy to one level with high and low water at Wexford. The whole fall is nearly absorbed in the first eight miles of the river from the former town.

An Act for the improvement of the harbour, in connexion with the embanking of the slob lands, was obtained in 1846, whereby the formation of a tidal reservoir, by the enlarging of the channel up to Enniscorthy, was provided as an equivalent for the reduction of the tidal basin, by the embanking; the estimated cost of the works was stated at £140,000, and that was taken to be the capital of the Company, but instead of attending to the conditions of the Act, so far as the improvement of the harbour was concerned, the Company confined their operations to the partial dredging of the sailing channel, without increasing the tidal reservoir, which could only be gained in the river, but they embanked and reclaimed 2,360 acres of slob land, valued by Mr. Griffith at £24,000, and adding one-third, according to the rule to ascertain the letting value, would give £32,000 as the value of a property obtained at a cost, in actual work (omitting parliamentary and other expenses), of about £7 per acre. Here for a time the improvements ceased.

In 1852 the Wexford Harbour Improvement Company obtained an Act by which they became the Wexford Embankment Company, and got relieved from the works of navigation of the Slaney undertaken under the Act of 1846. By the Act of 1852 the Lords of the Admiralty were empowered to appoint Commissioners for the purpose of constructing works for improving and deepening the harbour of Wexford, and the Embankment Company were to pay the Commissioners

£20,000 towards the improvement of the harbour, in addition to an annual charge in liquidation of the conditions imposed upon them by the Act of 1846. Two instalments, of £5,000 each, were paid by the Company up to 1854, but these sums being small, compared with what was required, it was determined by the Admiralty to wait until the funds had increased, and not to attempt any works before a sufficient sum could be made available; in 1858, however, the ship owners having become importunate, the Admiralty were obliged to yield, and purchased a steam dredger and barges, which worked for some time with beneficial effect, but the Embankment Company having ceased to pay their instalments, and the funds being exhausted, further operations were stopped, and much of the benefit conferred was lessened by storms acting on the shifting sands, no attempt having been made to secure Roslaire Point, or the Dogger Bank.

Although very little has been done since obtaining the Act of 1852, except reclaiming another portion of the slob land, containing about 2,400 acres, yet the correctness of the method for the improvement of the harbour as laid down by Mr. Farrell, in his Report of 1845, has been fully tested. The effect of the embankment of the mud lands, so as to cut off the north and south wings of the estuary, which allowed the tide to spread, instead of being forced up the harbour and rivers, is that there is an increase of six inches in the vertical range of the tide, or nearly one-eight of its whole mean range, and the progression of the tide wave has been so increased, that it is high water at Wexford quays twenty-one minutes sooner than in 1845. Thus, both the volume and height of the tide have been increased. The velocity and momentum of both ebb and flood, in the expanded portion of the basin, have been augmented, and the duration of the enlarged volume of flood tide has been prolonged at the mouth of the harbour, where it is of so much greater importance that the period of deeper water should be as great as possible.

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This success, though partial, leaves no reason to doubt if the sailing channel were dredged up to the quays at Wexford, the river deepened to Enniscorthy, and all impediments removed, that the contemplated results would be attained, and a very interesting problem in harbour improvement solved.

In 1859 Captain Vetch, having been a second time called on to report on the harbour, recommended that a cut connecting the Town channel with the Coal channel, should be made, but the cost of this was shown by Mr. Farrell in his Report of June, 1859, to be greatly underestimated, and quite out of the reach of the means of the local Commissioners, besides being likely to have the effect of silting up Hantoon channel, one of the most valuable entrances the harbour can have. Captain Vetch also recommended the construction of groynes or breakwaters, to be run out on either side of the channel upwards of 1,700 yards in length. These were also disapproved of by Mr. Farrell, as tending only to increase the conflicting condition of the tidal streams, and thus add to the extent of the bar.

To decide these questions, Mr. Coode, Engineer to the Harbour Works of Portland, was called in, being the last of fifteen eminent professional authorities who were consulted. Mr. Coode, in his Report dated December, 1859, states that, although the plan recommended by him for dealing with the approach to the harbour is, to a great extent, similar to that proposed by Mr. Farrell, yet he could not entirely concur with him, and he proposed a line of works or dykes along the north edge of the Dogger Bank, one thousand yards shorter than that proposed by Mr. Farrell, to be faced, in the absence of suitable material, with concrete blocks varying from four to eight tons, and filled in with the rubble stone of the country. He concurred in the recommendation to encourage the growth of the Dogger Bank into a permanent island. No works were undertaken in consequence of this advice, but in 1860 a new

Act was obtained to transfer from the Admiralty to a Special Commission, consisting of five (of whom a member of the Board of Works should be one), certain powers for the improvement of the harbour. In this, as in many other cases, it would almost seem, from the number of Acts of Parliament obtained to little purpose, as if there were a belief that legislation could supply the place of judicious enterprise.

The Harbour Commissioners were originally incorporated in 1794. Since that period they have received upwards of £100,000, of which £10,000 has been laid out in building quays and buoying the channel, the remainder having been spent in bringing water into the town, and for various other municipal purposes.

With this description of a very interesting engineering difficulty, we shall, for the present, conclude our notice of the subject of Harbours.

LIGHTHOUSES.

At what period lighthouses were first erected in Ireland, is not certain. It is stated in *Smith's History of Waterford*, that at Hooktown entrance to Waterford, a tall circular beacon tower was found standing by Strongbow when he landed near that place in 1070. In the reign of Charles II., a duty was first laid on vessels according to their tonnage, to maintain 6 lighthouses on the coast of Ireland; and a patent was granted to the Earl of Arran for that purpose. In the year 1703, the Irish Parliament, having ascertained that 2 only of the 6 lighthouses were maintained, revoked the patent, and entrusted them to the management of the Commissioners of Revenue, from whom they were transferred to the Ballast Board, under an act of the Legislature passed in 1810, empowering that body to erect new ones, and all towers, beacons, and sea marks necessary for the protection of shipping.

Up to 1768, the period of the completion of the south-wall lighthouse, which was first illuminated with candles, the clumsy expedient of coal fires was had recourse to, and these, as may be supposed, were liable to be extinguished in times of storm when they were most needed. These beacon-towers, as they should more properly be called, having been placed in the highest situations afforded by the neighbourhood, were, for that reason, often in the region of fogs, and to remedy that defect, the Howth light was transferred from the top of the hill to the lower position of the Little Bailey, where it now stands. It is found generally inexpedient to exceed heights of from 150 to 200 feet above high-water mark; however, in a few instances, that limit has been, of necessity, exceeded, as, for instance, Wicklow Head, Upper, is 250 feet above high water of spring tides; Minehead, county of Waterford, 285 feet; and the Great Skellings, county of Kerry, 372 feet.

Fifteen lighthouses were in operation at the period of the transfer to the Ballast Board, by whom they were either entirely rebuilt or repaired, and a new apparatus added. Up to the year 1818, when a return was made to parliament, 9 new lighthouses had been constructed, of which the Tuscar, on the east coast of the county of Wexford, was the most important.

The Tuscar lighthouse is situated on a rock, about 7 miles from Greenore Point, the south-eastern extremity of the coast of Wexford. The rock is about 300 feet in length, 150 in breadth, and its highest point is 30 feet above the level of high water mark. Preparatory to the building, beams were laid horizontally and firmly bolted into the rock as a foundation, on which a platform was laid, and huts built for 40 workmen. This preparation had not been long made, when, in October, 1812, a storm carried away the huts with most of the inmates, a few only having escaped by a timely retreat

to the highest point. The experience gained by this catastrophe was not thrown away on the Ballast Board, who adopted, as a guide, Smeaton's mode of construction of the Edystone lighthouse, which had been just then finished. The stone was procured from the granite quarries of the Dublin mountains, and each course was fitted and numbered before being transmitted to its destination.

The building, erected at a cost of £35,000, is circular, and 82 feet in height from low-water mark, at the level of which it is founded. The light, a revolving one, was exhibited for the first time in June, 1815. The Smalls lighthouse, near the Lands end, was carried away by the storm above referred to, rendering its reconstruction on a better principle necessary; both have since withstood the force of the sea.

From 1818 to October, 1854, the date of the Merchant Shipping Act, by which the control of the lighthouses was transferred to the Trinity House and the board of Trade, 49 additional lighthouses were built, making, in all, 73, besides 5 floating lights in situations where towers could not be constructed. The first floating light was placed in November, 1811, on the great sand bank called the Kish, part of a line of shoals extending, under various names, from the coast of Wexford to within 9 miles south-east of Dublin bay. Previous to the establishment of this light, vessels running for Dublin could not venture to stand in at night.

The iron houses, on account of their comparative novelty, are worthy of some notice.

The Fastnet Rock Light.—The site was selected as a substitute for the Cape Clear light, being four miles farther to the westward and southward, and less liable to be obscured by fogs. It was commenced in 1851, and completed (from the design of Mr. Halpin) in 1853, when the light was first exhibited. The Messrs. Mallet of Dublin were the contractors for the outer casing of the tower of cast iron, which is lined

with a cone of masonry for the first story, and for the remainder with brickwork, independent of the outer iron casing.

The rock, said to be silurian slate, stands high above the water, and the iron conical tower is based upon a bed levelled for the lowermost ring, which is secured by leaded lewis bolts. It is about 80 feet in altitude to the gallery, and 24 feet diameter at the base, surmounted by a lantern of iron and bronze, containing a revolving dioptric light, the upper and lower portions being fitted with catadioptric zones. The whole height from base to vane being 92 feet; and from the level of high water of springs 148 feet. The cast iron plates of which the tower is formed externally, are each about 8 feet by 3 feet in width, with flanged joints placed together, surface to surface, for the whole breadth of the flange, the vertical courses breaking joint with each other to the extent of half the depth of a plate. The average thickness of the shell is one inch and a quarter.

The gallery is carried out over the summit of the tower on a bold caveto running all round with a projection of about 5 feet. The whole structure was first erected on a levelled base in the foundry in Dublin, and, its parts being numbered, were sent by sea to their destination. Although the best period of the year was chosen, great difficulty arose in landing the parts on account of the heavy ground-swell of the Atlantic ocean, and the sheer dip of the rock on all sides to a great depth, rendering it necessary to step a derrick nearly horizontally out and suspended from the cliffs, by which means the several castings and stores were lifted vertically from the boats and swung to land. A storm having occurred during the progress of the construction, the workmen were saved from being washed off by taking refuge within the iron barrier of the first ring of the tower, which fortunately had been bolted down.

The whole constructed at a cost of £18,947 is a creditable

specimen of what can be done in Ireland, when opportunity offers, in this difficult branch of engineering, and will bear comparison with the best and latest works of the kind executed in England or France, where the construction of lighthouses has, in latter years, received great attention.

Two sheet iron structures have been erected supported on screw piles, patented by Mitchell, one on the Spit Bank, in Cork harbour, in 1853, the other in Dundalk harbour in 1855. They are similar in construction, octagonal in form, and each is borne on 9 wrought-iron screw piles, placed apart in the angles and centre, leaving the space beneath open. Height from base of screws to vane 72 feet, height from high water to vane 33 feet. Cost of each, including lantern and dioptric light apparatus, £6,412 9s. 3d.

One of the Carlingford lighthouses is a good example of cut stone masonry, constructed under circumstances which must be considered one of the best tests of engineering skill. It is built on a rock which bares only at low water of spring tides. The vane is 101 feet above high water. The light was first exhibited in 1823, and is visible at a distance of 17 miles with the naked eye. There is also a half-tide light placed below the other and shown at and after half-flood.

No separate external lightning conductor exists, but there is the usual arrangement of an iron hand-rail to form a continuous conductor from the lantern to the base of the tower. The cost, owing to the difficulty of the site, was £28,396 The average cost of construction of Irish lighthouses generally, including dwellings and illuminating apparatus, is about £10,000.

Although much has been done in the last half-century in marking and buoying, still the number of lights is admitted to be insufficient, more particularly on the west coast of Ireland; the lighting apparatus is also, in many instances, of an inferior description, and, comparing the proportion between

the number of lighthouses and the extent of coast line in England and Ireland, there is one for every 14 nautical miles in the former, and only one in every 35·5 miles in the latter; and yet upwards of three-fourths of the illuminating apparatus in use on the Irish coast is of the catadioptric description, and is not allowed to be replaced by the dioptric light when required, unless the old apparatus be worn out, although found insufficient, and affording a continuously diminished light during the successive stages of the reflectors becoming worse.

On the transfer of the controlling power to the Trinity House and Board of Trade, a balance of £100,000 was transferred to the latter, objections, however, tenable only by the force of authority are raised against supplying admitted deficiences on the Irish coast out of that sum, of which £23,000 only have been since expended, not amounting in the whole to the annual interest of the fund. The Board of Trade state, as a general rule, that they have no objection to lighting and marking bays, which may be considered, or may serve as harbours of refuge, provided there is no port inside them, but in the latter case they always refuse; consequently an important question has arisen as to what constitutes a harbour of refuge, or, in other words, what serves for local and what for general purposes, both being alike attained by the same means. The scope for interpretation on that point may be judged of by the following involved sentences in the Report of the Commissioners on Harbours of Refuge, 1859, which, no doubt, serves as an appropriate text for comentary from the highest authorities :—

"The Harbours to which our attention has been principally drawn are those which are required upon such parts of the coast as, being much frequented, are without any adequate place of safety into which vessels can run, if overtaken by storm. In bad weather and contrary winds it is, doubtless, desirable that all vessels, and especially that class by which

the coast is chiefly frequented, should have harbours in which they can take shelter, for the purpose of avoiding the risks and wear and tear incurred by keeping the sea, and the loss of time occasioned by being driven back. That such harbours are of great service is sufficiently attested by the use, in that respect, made of the harbours of Holyhead, Kingstown, and Portland, in which 200, 150, and 110 vessels respectively have taken refuge at one time during the last few weeks—events of common occurrence—and, therefore, it cannot be denied that they contribute very materially, even if indirectly, to save both lifeand property.

"But it is obvious that harbours of this description, however great may be their utility, differ very widely in character from those rendered necessary for the purpose of saving life by the entire want of other than tidal and bar harbours on an extensive line of coast, much exposed to heavy on-shore gales, and the most largely frequented by the class of shipping least capable, under such circumstances, of keeping off a lee-shore; and, as these would appear to have a more especial claim on our attention, we shall distinguish them by the name of *Life* Harbours, leaving to those first-mentioned that of Refuge Harbours, by which they are already generally known.

"In weather such as has been described, ships being able to reach those ports only which are under their lee, it is clear that on any line of coast the greater the number of such ports the greater will be their safety; and the conclusion becomes inevitable, that the best system to adopt is the improvement of the existing ports, if they are in sufficient number, and if such a course is practicable. But, if otherwise, then, that the sites for Life Harbours, of which facility of access and sufficient shelter are the only essential requisites, must be sought at that spot on the coast which is most generally accessible from every part of it, evidently, if it be straight at its central point, and if a bay at its head."

The case of the Copeland Light is worth notice, as being illustrative of the question of interpretation; strong representations having been made to the Ballast Board and Board of Trade that the light on Copeland Island, off the south-east entrance to Belfast Lough, should be taken down and replaced by one on Mew Island—which is a danger to be guarded against—a mile farther out; a committee of the Ballast Board, of which Lord Meath was Chairman, made an inspection of the locality, and reported in favour of the change. A Com-

mittee of the Trinity House made a subsequent inspection, and concurred in the views of the Ballast Board; but the Board of Trade, on the ground that it was more a harbour light than for general trade, refused to give their sanction unless the Belfast people were willing to contribute to the expense of construction by levying a tonnage on shipping, and yet Belfast is, unquestionably, a Harbour of Refuge, and the Copeland was selected by the Revenue Board, in 1796, as a sea light required in the locality to guide vessels navigating the east side of St. George's Channel, or thence passing into or out of Belfast lough, or Donaghadee sound. A bell was also amongst the requirements sought, on account of the fogs to which the coast is subject, arising, as supposed, from the very extensive back-water of Strangford lough; this, as well as Carlingford lough, and the harbours resorted to on the coast from Belfast to Dublin being tidal cannot be considered harbours of refuge, but Carlingford lough has, notwithstanding, been selected by the Commissioners of Harbours of Refuge as suitable for that purpose.

The Report of the Commission on Lights, &c., in 1861, in adverting to the complicated system of government, involving reference to three separate boards, states that "the Board of Trade has steadily kept economy rather than progress in view, but the saving they have thus effected has been represented sometimes as a false economy, and it has, unquestionably, led to much unsatisfactory correspondence, and, in some instances to prejudicial delay. Neither has the control of the superior over the inferior boards been always attended with a saving." The Commissioners further observe that, "four Special Committees of the Legislature have recommended that the expense of erecting and maintaining lighthouses, floating lights, buoys, and beacons, on the coast of the United Kingdom, should be defrayed out of the public revenue."

It is to be hoped that, independently of the large fund in hand, derived from an Irish source, that a policy will be adopted more humane as regards the taking of the necessary precautions for the saving of human life, and, with reference to the protection of property, more in accordance with the interests of a great maritime people, who are slow to admit, in any branch of their system of government, an inferiority which here undoubtedly exists.

ROADS.

THE comparatively early attention paid to the making of public roads in Ireland, is generally attributed to the abolition of the system of statute labour by the Act of 1763, giving to Grand Juries the charge of making highways by presentment; but that the movement had an earlier date, is proved by the Report of Colonel Roy, who was sent over in 1766, with a view to military defences. He stated that "there was no country whatever, where there were more, or, in general, better roads than in Ireland; that the Irish had been at great pains in this respect as well as in the building of bridges, for there were not only great roads leading from Dublin in all directions to the most distant quarters of the Kingdom, but likewise from every considerable town there were cross roads leading to the next adjacent places, and that manner of communication, he observed, was continued from town to town almost through the whole extent of the Kingdom. Arthur Young, who completed his tour in 1769, corroborates the above statement, but fell into error as to the Act quoted by him being the cause. He observed, "For a country so far behind us as Ireland, to have got suddenly so much the start of us in the article of roads, is a spectacle that cannot fail to strike the British traveller." And in referring to the Act of 1763, Young states, "The original Act was passed but

seventeen years ago, and the effect of it in all parts of the Kingdom was so great, that, (to use his own words), he found it perfectly practicable to travel upon wheels by a map. I could, he says, trace a route upon paper, as fancy would dictate, and everywhere I found beautiful roads without break or hindrance to enable me to realize my design." He adds, "What a figure would a person make in England who should attempt to move in that manner, where the roads are almost in as bad a state as in the time of Philip and Mary."

The mode of making roads, as described by Young, was to throw up a foundation of earth in the middle of the space from the outside. On that they formed a layer of lime stones, broken to the size of a turkey's egg; on that again, a thin scattering of earth to bind the stones together, and over all a coat of gravel. Considering the lightness of their carriages and the loads, he continues, "no fault is to be found with this mode, for the road is beautiful and perfectly durable under carts and coaches, the load for cars, which work regularly for mills in carrying flour to Dublin, being from six to ten hundred weight, but eighteen hundred weight has been often carried thither from Slane mills."

The next authority was Mr. Edgeworth, Civil Engineer, who published an Essay on Roads and Carriages in 1813. His method differed little from that described by Young, the stones being broken smaller, no stone to be larger than an inch and a half in diameter. According to his practice, a perch of a road 33 feet wide, would require about 15 cubic yards of broken stone, supposing the sides of the road to be weaker than the middle; the cost of repairs, as performed under his inspection, he estimates at less than one shilling per perch. He refers to a mode of breaking or pounding stones in his day by machinery, but it was found to reduce a portion of the material to dust; he therefore gave the preference to the long-handled small hammer.

He made provision for drainage, and laid it down as a principle, that the road need have no more curvature than would prevent it from being worn hollow before it could be conveniently repaired.

The improvement of carriages, as regards the principles of traction, was also fully treated by Mr. Edgeworth, and many errors of construction demonstrated by experiments.

In 1807, Mr. David Aher, in his capacity of Engineer to the Castlecomer Collieries, belonging, at that time, to the Ormond family, found great impediments to the supplying of the country with coals, on account of the want of means of communication with the markets, the mines being contained within the great mineral basin of Leinster, and accessible only over very high passes; he consequently was obliged to turn his attention to the construction of roads; in the accomplishment of this object, he laid out the line of road between Castlecomer and Carlow, over the Great Tolerton pass, which is 781 feet above the level of the sea; by this means he opened the country to the east. He next constructed the line from Castlecomer to Athy, passing through the centre of the Collieries and over the pass of Corgee, 870 feet above the level of the sea, thus opening the mines to the north and south. He afterwards laid out the road from Castlecomer to Kilkenny, also to Ballinakil, Ballyragget and the Clough district, completing the communication with the Collieries through mountainous districts, previously almost entirely excluded from commerce with each other. He subsequently laid out roads under the direction of the Post Masters-General, by whom, from the passing of the Act for making new roads in the year 1804, up to 1820, upwards of £40,000 were expended in making surveys; and during the same period, the cost incurred by Grand Juries in carrying them out, amounted to upwards of £300,000. The tolls payable by mail coaches amounted in the latter period to about £10,000 a-year.

Telford, previously to his being employed in the construction of the Caledonian Canal, was the first who gave his attention in England to the formation of roads, the subject having been considered, before his time, beneath the attention of an Engineer. He was subsequently employed, in 1806, by the Government to make new lines of road in the Highlands of Scotland, and there gained experience by which he profited in the construction of the Holyhead, Liverpool, and Great North roads, required by the increased communication with Ireland, after the year 1800.

Telford's method was to lay a foundation of large stones, with interstices between them for drainage, the layers of broken stone placed in the foundation, diminishing in size towards the top, so as to form, by the action of carriage wheels, a hard surface, having no greater convexity than was necessary to cause the water to run off freely. This system was much extended by Telford's assistant, Sir John Macneill.

In 1813, M'Adam gave evidence as to his system, before a Committee of the House of Commons, which had been sitting for ten years previously on the subject of roads without having led to any general practical improvement up to that time; for Mr. Edgeworth states that since his Essay was written (in 1813), he had visited England, and had found, on a journey of many hundred miles, scarcely twenty miles of well-made roads. In many parts of the country, and specially near London, he states that the roads were in a shameful condition, and the pavement of London utterly unworthy of a great Metropolis. About the year 1816, M'Adam, more as a professional road-maker than an Engineer, brought his method into general use in the vicinity of Bristol; it differs from Telford's method in omitting the foundation of large stones, and laying only a layer, 10 or 12 inches thick, of stones broken into pieces about 2 inches in diameter, and spread equally over the road about to be formed.

The remote and mountainous parts of the south and west of Ireland are indebted to the famine of 1822 for the further extension of good roads to those parts. In order to afford employment to the starving poor at that period, Mr. Griffith was appointed to the counties of Cork and Limerick, Mr. Kilally to Clare and Galway, and Mr. Nimmo to Ennis and Connemara. Very large sums were expended under the direction of these Engineers, by whom districts, theretofore inaccessible to the traveller, were opened up, the happy results of which have been steadily developing themselves during the time that has since elapsed. These extensions rendered the means of communication so complete that little remained to be done in that way when the employment of the people by the government again became necessary in the famine consequent on the potato failure of 1846, when the large sum of £11,000,000, nobly contributed by Parliament, had no other aim than the saving of the people, who were set to work at the repairs of roads, the cutting down of hills, and filling up of hollows, as a means of employment, and a labour test of destitution, rather than the performance of a work actually necessary to be done, seeing that the appointment of County Surveyors in 1834 had provided for all that concerned the construction and maintenance of roads and bridges, but, if a well-devised plan of trunk railways had been then initiated, and even partially carried out, a large expenditure would have been represented by a lasting improvement, and much capital saved to private individuals in the subsequent construction of railways competing with each other, instead of forming portions of a well-combined system, in which each part should contribute to the completion and advantage of the whole.

Amongst the roads of more recent date worthy of notice may be mentioned, that connecting the counties of Cork and Kerry, between Kenmare and Glengariff, a distance of 20 miles. It was commenced in July, 1833, under the direction

of Sir Richard Griffith, after a careful and rather difficult survey had been made through a mountainous district, the communication through which was of the wildest and most useless description, the principal road lying over the Eske pass, at an angle of 15°. The steepest gradient on the new road is 2° 30″. The pass at Dreenadrohur, 1,067 feet over high-water mark in Bantry bay, was chosen; through that pass a cut was made, upwards of 800 feet in its total length, the central portion being tunnelled, and 582 feet covered. The formation schist, traversed by veins of green stone and quartz, owing to its highly indurated nature, was found, in many instances, very difficult to be worked. The floor of the tunnel is 1,000 feet over high-water mark. Three minor tunnels were cut between the summit and Kenmare river. The latter is crossed by a suspension bridge, for which the site offered facilities. The Sound, as the part of the river crossed by the bridge is called, is divided into two channels by a rock, on this the tower of suspension is erected, with a half catenary on either side of it. The distance between the points of suspension is 313 feet; the versed sine 27·75 feet; angle of catenary 20″; length of platform 300 feet; vertical strength in tons per inch section, 8·2191, assuming the load it will sustain before it begins to stretch to be 12 tons per inch section, as calculated from the original design, by Mr. James B. Farrell. This road is quite Alpine in its character, and opens scenery unsurpassed in picturesque beauty, to which the views of Bantry bay and the Atlantic give the grandest effect.

The name of Sir Henry Parnell ought not to be passed over unnoticed. He published in 1833, a very excellent and comprehensive treatise on the subject of roads, with full details of the making of the Holyhead and Howth roads, between the years 1815 and 1830, upon which, including the Menai and Conway bridges, £759,718 were laid

out under Telford, being the great work of that day, undertaken for facilitating the communication between the two countries.

The principal improvement of modern times is the continuous maintenance of roads in the best possible condition, instead of, as formerly, putting on stones when they were allowed to get out of repair. The system, as laid down by Sir John Burgoyne, in a paper published by him in 1843, is that which is now generally followed.

The formation of tramways on public roads, to convey passengers, for which a Bill has been introduced in the present Session, is the revival of an old idea, as they were recommended to a Committee of the House of Commons in the year 1808; and had been some years previously actually in use at Milan.

BRIDGES IN DUBLIN AND THE VICINITY.

From the western to the eastern extremity of the Liffey there are 9 bridges, of these the most westwardly is Sarah, or Island bridge; the first stone of which was laid by Sarah, Countess of Westmoreland, in 1791; it consists of a single elliptic arch, of 104 feet span, 30 feet rise, and 38 feet in breadth, affording, with its abutments and side walls, a roadway 256 feet in length. Its height gives it a bold and picturesque appearance; and its dimensions generally entitled it to be considered one of the best specimens of bridge building of the period; being 7 feet greater span than the Rialto. The designer of it was Mr. Stephens, a Scotch Architect.

The second, or King's bridge, was built by public subscription, to commemorate the visit of George the IV. to Ireland, in 1821. But however useful in facilitating communication, it has very little of an ornamental or commemorative character to recommend it, being a very plain metal structure of one

arch, 102 feet span, and 11 feet 6 inches rise, composed of seven cast-iron ribs; the road-way is 30 feet between the parapets. The cost of construction was £7,000. The design was selected in preference to the handsome stone bridge with a triumphal arch at the southern approach, the plan of which is before the Institution, as submitted to public competition, by Messrs. Henry Mullins, and M'Mahon, at an estimated cost of 11,000. It would have formed a handsome feature in connexion with the imposing Terminus of the Great Southern and Western Railway, then not contemplated. There is said to be £1,500 unexpended, and in bank, of the sum subscribed for this testimonial.

The third bridge was constructed of wood, in the first instance, in 1671, and was called Bloody bridge, in consequence of some persons having been killed on it, in an affray, soon after the opening. It was subsequently built of stone, and took its name from the barracks in the vicinity. It was a plain structure of four semicircular arches, and the sterlings, on which the piers were built, in the usual fashion of the day, having encroached greatly on the water way, caused such under-cutting as rendered the whole unsafe. It is now being replaced by a handsome cast-iron arch, 95 feet on its chord line; with versed sine of 9 feet 6 inches. The abutments of masonry are 37 feet 8 inches in width, over the springing level across the pilasters. The bridge is to measure 122 feet 10 inches, from quay line to quay line, at the level of the road-way, which is 33 feet between the parapets. A contract has been entered into for the construction, amounting to the sum of £11,000.

The fourth, or Queen's bridge, formerly called Arran bridge, built in 1684, having been carried away by a flood in 1763, was replaced in 1768, by the present bridge, which got its name in honour of Queen Anne. It consists of three arches of hewn stone, making a length of 140 feet, and, with its

balustrade and ornamentation, is creditable to its designer, Colonel Vallency, whose name must always be honourably associated with the arts and literature of Ireland.

The fifth, or Whitworth bridge, reckoning from the west, consists of three arches, and much resembles Queen's bridge in design, its name is derived from the Viceroy who laid the first stone in 1816.

In sinking for a foundation for the south abutment it was found that the old bridge stood upon the ruins of another still more ancient, the materials resembling Portland stone. The masonry was built in regular courses, connected by iron cramps, and laid on a platform of oak timber, supported by small piles shod with iron, which, being oxidized and incrusted with sand, had preserved the timber as if petrified.

The sixth, or Richmond bridge, consists of three arches of equal spans, forming a road-way of 220 feet in length, and 52 feet in breadth. Built of Golden Hill granite, the keystones being ornamented with allegorical colossal heads, executed by Edward Smith. It is opposite to Winetavern-street, and occupies the site of the oldest, and for many years the only, bridge in Dublin. The original structure, the date of the construction of which is uncertain, having fallen in 1385, was rebuilt in 1428, by the Dominican Friars, who levied toll for the passage. Having again yielded to the hand of time; its ruins, long a discredit to the city, were carried away by a flood in 1802. The present bridge was commenced in 1813, and took its name from the Duke of Richmond. The design was given by Mr. James Savage, of London; and Mr. George Knowles, Civil Engineer, of Dublin, was the contractor, for the sum of £25,800, including the metal balustrade, which extends along the Quay in front of the Law Courts, and joins with that of the Whitworth bridge.

Edward Smith, the carver of the colossal heads, whose works of sculpture are numerous in Dublin, was the pupil of

Charles Vierpyle, who was brought over to Ireland by that distinguished patron of the fine arts, the patriotic Earl of Charlemont.

The seventh, or Essex bridge, was built in 1676, during the Viceroyalty of the Earl of Essex, from whom it received its name. The foundations having been laid on oak frames, resting on the natural bed of the river, became undercut, and fissures having taken place in the piers, their removal was determined on, and commenced in January, 1753. The present bridge was completed towards the close of the year 1755, at a cost of £20,661, under the direction of Mr. George Semple, Westminster bridge having served him for a model, every stone, as he stated in his description, being in exact similitude and in respective proportions with that structure, and the spans of the arches being to one another as three to five. Although Semple copied M. Labelye's design of Westminster bridge he did not adopt his mode of building the foundations in caissons, for having ascertained, from carefully made borings, the great inequalities in the rocky bottom of the river, he had recourse to coffer dams, a description of that contrivance having just then been published by Bellidor, and by means of which the foundations on the north side were laid 27 feet under high water.

Semple was no ordinary man, as may be seen by his *Treatise on Building in Water*, published in 1756; but the profession in his day having had a low standing in public estimation, neither money nor distinction were to be gained by talents such as he possessed, and after a useful and laborious life, dedicated to the advancement of Engineering science, he was obliged to apply to Parliament for a pension of £100 a-year, which he obtained, to maintain him in his old age.

The eighth is the iron bridge for foot passengers. It consists of one arch of 140 feet span; 12 feet wide; and 11 feet 9 inches rise, forming the segment of an ellipse, supported on

stone abutments. It was built as a toll bridge, on speculation, by Alderman John Claudius Beresford, and William Walsh, Esq., at a cost of £3,000, and was opened in the year 1816.

CARLISLE BRIDGE.

When the old Custom House was removed from the vicinity of Essex bridge, not without much opposition from interested parties, and a new one built in its present site, nearer the mouth of the river, vessels were no longer obliged to pass to any great distance upwards, and, consequently, Carlisle bridge was constructed, during the Viceroyalty of the grand-father of the present accomplished and popular Chief Governor, who has proved himself not unmindful of the association of his name with our earlier efforts at creditable and lasting improvement. Designed, by Gandon, it consists of three semicircular arches, the centre being the greatest span, and forming, together, a road-way 210 feet in length, and 60 feet between the parapets. The foundations were laid in caissons. The building was begun in 1791, and was finished in 1794, at a cost of 60,000. The allegorical heads forming the keystones of the arches, and the other ornamental work, in Portland stone, are by Edward Smith, in his best style. By the opening of this bridge the extension of the city took a new direction, and the most important improvements, such as the building of Westmoreland and Sackville-streets were amongst the results.

Mr. Gandon, who was a pupil of Sir William Chambers, came to Ireland in 1781, under the patronage of a distinguished lover of art, the Earl of Charlemont; a nobleman who established an additional claim to the gratitude of his country, by introducing the designer of some of the most ornamental public buildings of its chief city. Gandon was a man of great

natural ability and extensive acquirement, as well in the constructive as in the artistic part of his profession, and has left us, in the Custom House, the eastern portico of the Bank of Ireland, the central portion of the Law Courts, and the King's Inns, monuments, which need no inscription to perpetuate his name.

In the letters published with the interesting memoirs, edited by Mr. Thomas J. Mulvany, Gandon refers to the hurried manner in which he was obliged to prepare the design and to commence the building of the Custom House, through fear of its being stopped by the threatened opposition, and in this excuse he seems to have anticipated the objections to the defective lighting of the building, to which it is undoubtedly liable.

With reference to the site—a portion of a swamp, nearly a square mile, extending from the Liffey to Annesley bridge, always overflowed by floods, and by spring tides—he became much alarmed at the difficulties it presented to forming a solid foundation, but the supposed impracticability of the undertaking had, on the other hand, the effect of abating the violence of the opposition, and of allowing the work to be proceeded with in anticipation of failure, which was, however, skilfully provided against. In sinking for the foundations of the walls of the cupola, the hard gravel was found 8 feet below the surface, and to test further the nature of the strata, a pile 10 feet long and one foot square was driven down 9 feet, beyond which the ram ceased to move it, indicating, as was generally supposed, the propriety of a piled foundation, but Gandon judged differently, for he observed a small stream of water rising up close about the pile, as if it had pierced a spring, he, therefore, had recourse to a strong grating of Memel timber, the interstices of which were filled in with stock bricks laid in mortar, composed of powdered roach lime and mortar well-mixed, supposed to be equal to Tarras, over

this was laid a strong flooring fastened down on the grating, rendering the platform complete, on this the walls were raised with rough blocks of mountain granite, in the first course of which was sunk a chain bar of flat iron. I have thought this instance of the skill and judgement of Gandon not unworthy of notice, more particularly as on a comparatively recent occasion the stability of an important work on the Shannon, to be referred to hereafter, was proposed to be endangered by piling in a porous bottom.

Looking to the architectural and engineering works designed and successfully carried out by Gandon, and his literary and artistic performances in publishing a continuation of Campbell's *Vitruvius Britannicus*, engraving many of the plates with his own hands, and translating the descriptions into the French language, he must be considered to have rivalled the best men of the continental schools of his day; he was also amongst the last who exercised with distinction the combined professions of architecture and civil engineering, and having adopted the scene of his professional triumphs for his residence, and the investment of his savings in building a portion of Beresford-place, he died in 1822, in the 82nd year of his age, at the then fashionable resort, Lucan, in a villa of his own design.

After the lapse of a little more than half a century from the date of its construction, Carlisle bridge has become insufficient for the great thoroughfare over it, and a suggestion has been, in consequence, made to take it down and build another of greater breadth, at a cost of £40,000, but, seeing that the structure shows no signs of instability or dilapidation, an obvious and cheap remedy presents itself, in placing the foot-paths on brackets outside the parapets, thus affording 7 carriage ways in a space of 60 feet, which would be ample for the passage of vehicles over it. This course is the more to be recommended, seeing that the line of traffic parallel to the

river must always be a cause of obstruction, notwithstanding any extraordinary breadth of the bridge, and that there can be no effectual easement of a crowded passage so circumstanced, except by diverting a portion of the traffic to another part of the river, a suitable place for that object appearing to be above the Custom-house, leading to Gardiner-street at one side, and to Brunswick-street at the other, thus opening another communication with the north and south sides of the town, rendered necessary by the increased population of the North Lots, and the great transit trade carried on from the North Wall. It should also be borne in mind that the very slight rise of the crown of the centre arch of Carlisle bridge over the level of Westmoreland-street leaves no means of effecting any considerable lowering by a new structure. A bridge over the Custom House might be so constructed as, at a future date, to have a second storey, or high level for railway communication between Kingstown and the Midland and Drogheda lines.

LUCAN BRIDGE.

This structure, consisting of a single arch of 111 feet span, and 22 feet rise, like many of the same period, is of a far more expensive character than the occasion called for. Its construction was attended with no difficulty, a good foundation having been easily obtained, with suitable materials immediately at hand, and yet the cost of construction exceeded £9,000. Mr. George Knowles was the architect and, probably, the contractor, an arrangement common in those days, owing to the difficulty of obtaining the services of a sufficiently competent person of the latter class, together with the want of capital, there having been no banks to assist enterprise of that description.

Drumcondra bridge, which was commenced in 1813, is supposed to have been the work of the same architect. Its cost was £3,000.

The description of other bridges worthy of notice shall be given when time for collecting the materials can be afforded.

SURVEYS AND REPORTS ON BOG IMPROVEMENT.

The first step towards a general system of land improvement was taken by the Irish Parliament in 1715, by passing an Act to encourage the drainage and improving of the bogs and unprofitable low grounds, and for easing and despatching the inland carriage and conveyance of goods from one part to another within the kingdom. Under this Act Members of Parliament and others were appointed commissioners, with power to nominate undertakers, and, although much was contemplated, little was done, more particularly as to drainage, the works executed having been principally for navigation purposes, and undertaken at a later period as already described. There are, however, remains of works to be met with commenced with the view of opening up the outfalls of the drainage of important districts, but no extensive or permanent relief was afforded, owing to their having been left incomplete.

A systematic project was inaugurated in 1809, under the Commissioners of Bog Improvement, when surveys were undertaken, and maps made, of the principal bogs of the country. The Engineers employed for that purpose were Messrs. Griffith, Jones, Longfield, Townsend, Brassington, Aher, Colbourne, Edgeworth, Bald, and Nimmo, with a staff of forty native surveyors. This Commission lasted three years, and has left us three volumes of reports and maps, containing much valuable information on the features of the bog districts

generally, the nature of the peculiar mosses of which they are principally composed, and the means of their improvement.

The following conclusions were arrived at, aided by the Ordnance Survey, executed by General Vallancy, who was Chairman of the Commission:—1st.—That the principal bogs, not including mountain bog, nor those less in extent than 500 English acres, amounted to 1,013,358 acres; 2nd.—That about six-sevenths of these are contained within a space of little more than one-fourth of the entire superficial extent of the country, included within a line drawn from Wicklow-head to Galway, and another drawn from Howth-head to Sligo, forming a broad belt across the centre of the island, with its narrow end towards the capital, and gradually extending in breadth as it approaches the Western Ocean; 3rd.—That this tract, extending from east to west, is crossed by the Shannon from north to south, dividing it into two parts, of which that to the westward contains more than double the extent of bogs to the eastward, the latter being in extent about 260,000 English acres, most of this, occupying a large portion of the King's county, and county Kildare, is known as the bog of Allen, being, however, composed of a number of distinct bogs bearing that name, although separated by elevated grounds; it was computed that there were besides not less than 560,000 English acres of detached flat bogs, scattered through other counties of Ireland, and that 1,255,000 acres of peat soil form the covering of mountains in the counties of Wicklow, Donegal, Tyrone, and Fermanagh, and the districts of Erris and Connemara; making an aggregate of 2,828,358 statute acres of peat soil in Ireland, caused by humidity and a low state of temperature, aided by want of drainage; the peculiar moss of which bog is principally composed being so retentive of moisture that it will grow to a depth of 20 or 30 feet on the sloping sides of steep hills, and of this fact some remarkable instances are given.

No works of drainage were undertaken under this Commission, the object of it appearing to have been the obtaining of information to enable private individuals to make profitable outlay in improvements of the nature described, great advantages having been anticipated. The results, however, were far from encouraging, as an erroneous system was adopted, the efforts of the proprietors having been confined to superficial drainage, and the application of manures as practised in the attempted reclamation of Chatmoss, but in the absence of any provision for opening the outfalls of the water courses commanding the drainage, the tendency of the soil to revert to its natural state of aquatic moss rendered permanent improvement hopeless, each successive application of manure getting buried in the bog, and requiring constant renewal to obtain a crop while it remained near the surface.

This subject has been treated of by the late Mr. Mullins and myself in the second volume of the *Transactions of the Institution*, wherein principles are laid down better suited to the attainment of the object in view than those generally adopted.

The first efforts at bog improvement were made in 1760 by Mr. Trench, of Woodlawn, afterwards Lord Ashtown, as described by Arthur Young. About 300 acres are said to have been reclaimed by superficial drainage and the various applications of clay, limestone, gravel, and stable manure. This early example of alleged success does not appear to have led to any extensive operations of a like nature; nor did the labours of the Commissioners, however creditable as surveys and reports, give rise to any improvements deserving of record, the system of superficial drainage being unsuited to the purpose of permanent reclamation.

The cost of the Commission, which existed from September, 1807, to December, 1813, was £37,221.

SHANNON.

The river Shannon passing through 9 counties out of 32, and affording 230 statute miles of continuous navigation; 71 miles, from its mouth to Limerick, being a tide-way, with a flood 20 feet in height at the city quays, offered such prospects to the inhabitants on either side of the borders, 460 miles in length, as to have created early attention to its improvement, which has been already described, but that improvement, although apparently adequate to the trade, not having produced the desired effect, an idea was taken up that the drainage of the flooded lands would be attended with more beneficial results than any improvement of the navigation; it was accordingly proposed in 1821, to lower its waters, and with the view of carrying out the project Mr. Rennie, who was directed by the Government, in the year 1821, to have a survey made of the river, appointed Mr. Grantham for that purpose. He produced a valuable report, with an accurate survey of the whole river. The estimate of the work, by which 2,000,000 acres were proposed to be drained, was £300,000. This scheme was, however, abandoned at the death of Mr. Rennie, and the river left in its previous condition.

Mr. Alexander Nimmo, in his evidence before a Committee of the Lords, in 1824, stated that "the Shannon had been made navigable into lough Allen, but there were no quays or roads to the water at any part of the river, except at the bridges, and that £4,000 or £5,000 would accomplish all that was wanted, in making roads and landing-places."

The notion, too often acted on, that increased facilities will produce trade, where little or none previously existed, was again the cause of a very extensive plan of improvement.

A Commission, consisting of Colonel Burgoyne, Captain Mudge, R.N., and Thomas Rhodes, Esq., C.E., was appointed

in 1831, for the purpose of taking into consideration the navigation of the Shannon, as well as that of its tributaries, as also the practicability of draining, in an effective manner, the lands subject to winter and summer floods. Captain Mudge, R.N., described the state of the lower Shannon from Limerick to the sea, and of the river Fergus from Ennis and Clare, to its junction with the Shannon. M. Rhodes reported on the state of the river from Limerick to lough Allen, together with that of its numerous and important tributaries. Sir John Burgoyne gave such inspection and co-operation as his position of Chairman of the Board of Works, then about to be formed, would permit.

In 1833 the principle of the whole scheme of navigation and drainage conjoined was laid down by M. Rhodes, as published in the first Report of the Commission; and in 1837, under the Act of the 5th & 6th Wm. IV., cap. 67, Colonel J. F. Burgoyne, Captain Jones, R.E., Richard Griffith, William Cubit, and Thomas Rhodes, Esqrs. Civil Engineers, were appointed Commissioners. In the same year the second Report, with the plans and estimates, was published, comprising the special consideration of the intended operations, from the mouth of the river up to Tarmonbarry, where the Royal Canal enters. In 1839 authority was given to the Commissioners to proceed, and in 1840 the works were commenced.

In the main portion of the Shannon, extending from the sea up to Limerick, with the exception of the little harbour at Foynes, nothing was contemplated but the erection of beacons and buoys to mark the sailing course, and from the confluence of the Fergus with the Shannon to the village of Clare, 2 miles below the town of Ennis, the improvement was confined to works of accommodation, such as quays or piers, of which one or other was constructed at Querrin Creek, Kilrush, Ballylongford, Kiltesey, Kildisart, and Clare on Fergus.

From Limerick to Killaloe, a distance of 15 miles, there is

a rise, from the tide water to the surface of lough Dergh, of 97 feet, causing so rapid a current at both extremities, as originally to have obliged recourse to be had to side canals, of which there are 8½ miles, with 11 locks of various sizes, as already described, and 6½ miles of river navigation. Seven locks had been formed at the Limerick end, terminating in a harbour, with a lock communicating with the tide-way in the city, and 3 locks at Killaloe, making the number above stated completed up to the year 1812.

It having been considered impracticable to render this portion of the river navigable for large steam vessels, the original plan was not disturbed, but to guard against the rapidity of floods in the river course, and to maintain a sufficient depth in dry weather 2 extensive regulating weirs were constructed, 1 at Corbally, and a second at Castleconnell.

The rapids at O'Brien's bridge and Parteen were deepened, many shoals removed, and embankments constructed, in order to preserve the course of the navigable channel, and there having been no means of underpining the piers of O'Brien's bridge, owing to the original defectiveness of the construction, 5 new arches, each 27 feet span, were added at its eastern end, in order to give a sufficiently rapid discharge in time of flood. A bridge, 416 feet in length, and 8 feet wide, supported on timber piles, was also erected at Plassy, for the passage of track horses.

It is an old opinion among Engineers, and one participated in by Smeaton, that side canals prove, eventually, to be more effective than making channels in the beds of rivers, and that for the purposes of navigation, rivers should be used to supply canals with water. The system formerly adopted for the works of this river, in pursuance of that opinion, was to avoid every rapid by a side canal, and to have a lock for a fall of 1 or 2 feet only. The plan of the Shannon Commissioners, as suggested by Mr. Rhodes, from Killaloe upwards, was the

erection of locks and regulating weirs at the great falls, the extension of the levels to considerable lengths, and the removal of the intervening shoals by excavating or steam dredging. The middle and upper portions of the river, extending 122 miles in a northerly direction, from Killaloe to lough Allen, the whole fall being 46 feet 5 inches in that distance, were subjected to the altered system, the peculiar character of the Shannon, in these portions, consisting of lakes connected by a broad sluggish river, of which the depth, except at the shoals, varies from 10 to 20 feet, offering the most favourable conditions for a combined plan of drainage and navigation; the 3 great lakes, or reservoirs, forming 50 miles of the whole line, which, in Mr. Rhodes survey of 1833, were reported to be sufficiently deep for navigable purposes at the lowest summer water.

The principal works were the locks and weirs connected with them at Killaloe, Meelick, Athlone, Tarmonbarry, Rooskey, and Jamestown, constituting 5 reaches, into which the whole scheme was divided, to regulate a fall of 46 feet 5 inches in 122 miles.

The object of the weirs was to pen up the waters, so as to preserve in the driest seasons a depth of at least 6 feet 6 inches in the shallowest parts, and, at the same time, by extending their length considerbly beyond the direct breadth of the river, and by removing all obstructions to the current from below the falls, to produce such an increased rapidity in the discharge, in wet seasons, as to prevent the flat meadow lands adjoining the river banks being flooded, as they were during a great portion of the year.

Killaloe having a shoal extending quite across the river, and being at the southern end of lough Dergh, which has an extent of 23 miles in length, and from 2 to 9 miles in breadth, was the key of the drainage. Mr. Rhodes observed that in the winter of 1832 the water rose to the height of 15 feet

above the upper sill of Killaloe lock, and as the canal was constructed for 6 feet water, a depth ample for the class of vessels trading on it, he inferred that the increase from summer to winter water was 9 feet. To prevent that accumulation was the great object in view, and in order to its accomplishment he determined, besides excavating and widening a part of the channel above Killaloe bridge, to construct a stone weir of eliptic form, and of solid masonry, 1,160 feet in length, bedded into the rock, of which the bottom consists, the eliptic curve having appeared most suitable for discharging the greatest quantity of water in the least time; this weir to be made of such height as to retain, in the driest seasons, 6 feet of water upon the sill of the Killaloe lock. It was calculated that the weir would give much more than double the discharging power of the old channel, and that not more than a depth of 2 feet 6 inches could ever accumulate on its apex at the maximum, and that the winter floods would thus be lowered 6 feet 6 inches, a reduction considered to be abundantly sufficient to keep the waters of lough Dergh and the Shannon at all times within their banks. Extensive improvements were also made in the water ay at Killaloe bridge, to which three arches, each 30 feet span, were added, and the whole of the piers of the bridge under-pinned to a depth of 5 feet below the original foundation.

Previous to the operations being commenced, the usual difference between the level of summer and winter water at Killaloe, and through lough Dergh, was from 10 to 12 feet.

The Middle Shannon, extending from Portumna, at the northern end of lough Dergh, to Athlone, at the southern end of lough Ree, comprises 36 miles of a broad, deep channel, the whole, as described by Mr. Rhodes, in his preliminary survey, being generally of sufficient depth for the navigation of the largest class of steam vessels, and for drainage purposes at low summer water, with the exception of 15 fords, of which

Meelick was the principal one. These shoals are described as of small extent, and nearly all of them composed of the same material as the other parts of the bed of the river, forming natural ridges of mountain clay, limestone gravel, and detached stones. The rise from the surface of lough Dergh to lough Ree is 16 feet, and was formerly rendered navigable by short lateral canals to avoid the falls, with 4 locks of various lifts. Two of these locks were dispensed with, one at Banagher and the other at Shannon bridge; of the two retained, one was placed in a new side cut of 1,000 yards in length at Meelick, 9 miles above the northern extremity of lough Dergh, and the other in the bed of the river at Athlone, close to the southern extremity of lough Ree. The Meelick weir, 1,100 feet in length, is built convex in form, of solid masonry, between 2 rows of piles, 30 feet in breadth and 6 feet 9 inches in height, with retaining walls on either side 200 feet in length. The lock is a fine hewn-stone structure, 170 feet in length and 40 feet wide, with a rise of 8 feet. The lower sills of this and the Athlone lock were laid so as to have 7 feet water on them in case it should be found necessary to deepen the river channel to the same extent at a future period.

At Shannon bridge the piers were under-pinned to the depth of 6 feet below the old foundation. Between Banagher and Shannon bridge, about a mile from the former, the Grand Canal enters on one side, distant from Dublin 79 miles, and on the other side, from Ballinasloe, 13 miles distant.

The Athlone weir, like that at Meelick, is also convex, and of solid masonry, built between 2 rows of piles, 38 feet in breadth and 6 feet 9 inches in height. The lock, built of finely-dressed cut stone, is 155 feet long by 40 feet wide, with a pier 284 feet long by 30 feet wide. There was also removed from the bed of the river, between the weir and lough Ree, a very considerable quantity of excavation, of which the foundation of the old bridge formed part.

Lough Ree, in a length of 18 miles, presented but three unimportant obstructions; one at Lanesborough, situated at the northern extremity of the lake, gave a fall of about a foot, which was formerly passed by a lock, from thence to Tarmonbarry, a distance of 8 miles, there was no difference of level worth notice, and the removal of the slight obstruction at Lanesborough, gave a continuous deep and wide channel, from Killaloe to Tarmonbarry, of 85 miles in extent, with but two locks as already described. This may be properly called the main portion of the navigation, on which 3 bridges, deserving of notice, were built: one at Banagher, consisting of 6 eliptic arches, each of 60 feet span and 32 feet roadway, with an iron swivel bridge for navigation, having an ope of 40 feet in breadth; one at Athlone of 3 arches, each 61 feet in span, 32 feet roadway, having also an iron swivel bridge of the same ope as that of Banagher, 22 feet 9 inches in width; a third at Lanesborough, having 5 arches of 30 feet span, with a swivel bridge of the same ope and width.

From Tarmonbarry (where the Grand Canal enters) to the town of Leitrim, a distance of 30 miles, the Shannon is generally broad and deep, widening at intervals into seven small lakes, the aggregate length of which is $11\frac{3}{4}$ miles, and the largest of them, lough Forbes, 3 miles long and $\frac{1}{2}$ mile wide. In the whole distance the fall amounts to 18 feet, which was formerly passed by lateral canals and 3 locks, namely, at Clondragh, Rooskey, and Jamestown.

The works in this division are of similar character to those already described, but were executed on a reduced scale; the 3 locks constructed, namely, at Tarmonbarry, Rooskey, and Jamestown, being each 110 feet in length and 30 feet in breadth. There is also a pier to the Tarmonbarry lock 224 feet in length by 30 feet wide. Rise of lock 8 feet 7 inches.

Regulating weirs, convex in form, have also been constructed in connexion with each of these locks, one at Tarmonbarry

520 feet in length; two at Rooskey, whose aggregate length is 744 feet; and one at Jamestown, near the head of the side canal, 750 feet in length. New bridges have likewise been erected at Rooskey, Jamestown, and Carrick; that at Rooskey having a swivel of 30 feet ope. Wharves have also been built at Tarmonbarry, Rooskey, Drumsna, and Carrick.

Between Rooskey and Drumsna, the Carnadoe river joins the Shannon, and was made navigable for 6 miles through the Gillstown lake, situated within 3 miles of Strokestown.

At Drumsna some deepening of the river and under-pinning of the bridge took place; and at Jamestown, in addition to the weir, a new bridge was built of 5 segmental arches, each 30 feet span and 17 feet wide between the parapets.

At Carrick, 20 miles above Tarmonbarry, the Boyle water, the first great tributary of the Shannon, enters, and has been made navigable for a distance of 9 miles through lough Key to within a mile of the town of Boyle. The works are on the same scale as those of the division in their neighbourhood. They consist principally of a lock and regulating weir at Knockvicar, and a bridge of three 30 feet arches with an over fall above it 244 feet in length. The lock is 112 feet by 30 feet, with a pier 200 feet by 25 feet. The rise of the lock 4 feet. The weir is constructed with a sluice. A bridge was also built at Cootehall, and a large quantity of excavation removed from the bed of the Boyle water.

From lough Forbes, near Tarmonbarry, to Leitrim, 5 miles above Carrick, numerous shoals, consisting of rock and gravel, were removed.

At Battle bridge, near Leitrim; the lough Allen canal enters the Shannon, extending 3 miles to Drumshambo, little alteration was here made, the operations having been confined to the deepening of the canal and the under-pinning of the lock at Battle bridge to suit the altered levels.

The deviation of the course of the mountain river, the

Arigna, so as to discharge its waters into lough Allen instead of the Shannon, which was injuriously affected by the quantity of debris carried into it, was the only improvement in this quarter.

The Shannon takes its rise in the mountains of the counties of Cavan and Leitrim, to the north of lough Allen, which is the catchment basin of the surrounding district, and extends 10 miles in length from north to south, and 3 miles in breadth from east to west; the average depth is 12 feet. It stands 160 feet above the level of the sea at low water of ordinary spring tides.

The coal of the Arigna district not being obtainable in sufficient quantities to smelt the iron ore, found there in abundance, and of the best quality, the works have long since ceased; and of the coal raised for domestic use, but little finds its way to the Shannon, the first impetus to the trade of which is given at Carrick, no important addition to the tolls having as yet arisen from the lough Erne Canal, opened in the year 1860. It enters the Shannon at the town of Leitrim, 5 miles above Carrick.

In the execution of the works of the Shannon improvement, the great and sudden rise of the floods caused much difficulty and expense; but little however, on that account, was added to the original estimate, as the whole was judiciously let by contract, and the result, as well in that respect as in the permanency of the construction, justified the mode of letting adopted.

At Athlone, the coffer dam, within which the new lock was built, enclosed an area of 36,160 square feet, the height of flood water outside was about 24 feet, being 6 feet 6 inches above summer level; and the additional pressure of this increased height on the porous sandy bottom, extending to a great depth, rendered it impracticable as well as unsafe, to attempt the unwatering some time before the flood had

reached its maximum. Metal pumps, 15 inches in diameter, worked by three water-wheels and a powerful steam-engine, removed about 6,000 gallons of water per minute; but it was found that the water rushed in so rapidly in flood time, as to blow up the bottom and to endanger the safety of the coffer dam; and even at the ordinary level of the external river, the bursting up of the water in excavating for the foundation level, was so serious that it was contemplated to build on a wooden platform, supported by piles, but on more experienced advice, a bed of concrete, made with hydraulic lime, of excellent quality, found in the neighbourhood, was adopted, and what appeared to be a great difficulty, was easily and effectually overcome.

The temporary diversion of the Shannon at Athlone into the old canal, 50 feet in breadth, is not unworthy of a passing notice. There having been a large quantity of excavation to be removed from the bed of the river, consisting in great part of the foundations and sterlings of the old bridge, and of old walls and mill-dams, not removable by dredging, the unwatering of a considerable space therefore became a serious question, and it occurred to me that the making of a clay dam down-stream of the old canal, through which the Shannon as it leaves lough Ree might be turned, would afford an opportunity for a sufficient time to allow of the excavation being removed; with that view, the lock-gates of the canal having been kept open for some weeks in order to lower the surface of the lake, a dam was commenced immediately down-stream of the old canal, which is 50 feet wide, at a part of the river 530 feet in breadth, and from 4 to 8 feet deep. A sort of coffer was made, in the first instance, of hurdles, supported by short piles to prevent the clay hearting being washed away; this being done, a berm of stones was made on the down-stream side of the dam to give support. By keeping the lock-gates open, the surface of lough Ree was lowered

12 inches below its ordinary level before the closing of the dam, on the up-stream side of which, when closed, the water rose steadily an inch every 24 hours, and as a rise of 2 feet 6 inches could take place before the lands on either side were flooded, nearly 30 days freedom from water were obtained, and during that time the excavation was removed.

The circumstance of allowing the waters of lough Ree to run low in the dry season, as above described, exemplifies the effect of lowering the surface of the lakes in a combined system of drainage and navigation, supposing the river portion of the channel to be made to correspond, thus giving more capacity to the reservoirs, and more discharging power to the conduits leading from them; whereas, under present circumstances, the flooding is not prevented, although it is carried off with much more rapidity than formerly, and, as might be expected, the reach between Meelick and Athlone, 27 miles in length, into which the Suck and Brosna rivers pour their waters, is subject to the greatest rise of floods, the water being backed up to Athlone, so that all trace of the weir at that place disappears on the surface.

Such a result, under existing circumstances, is not to be wondered at, when it is considered that the catchment basin of the Shannon is about 4,000 square miles in extent, or 2,560,000 statute acres, of which 3,613 square miles are above Killaloe, and 385 square miles below it; the discharge at Killaloe weir, as ascertained by Mr. Mulvany, in February, 1849, at a period of high flood, was 1,108,660 cubic feet per minute; and taking the discharge from the mountain basin below Killaloe, 385 square miles in extent, at 369,300 cubic feet per minute, will give a maximum discharge at Limerick of 1,478,960 cubic feet, or about 41,230 tons per minute. It is, however, presumable if the channels had been made more capacious, and means adopted of regulating the discharge of the so-called *regulating* weirs, that no great

accumulation of water would have taken place, and that any approach to the former state of the river, which flooded for months together the low levels on its borders, would thus have been effectually prevented.

The successful navigation of the Shannon, with the certainty and despatch required for commercial purposes, was due to the introduction of steam vessels; for, although the new locks admit of large craft being used, yet these were unfit to encounter the dangers of the stormy lakes, and detentions, for long periods at Lanesborough and Portumna, during south-westerly winds, would have taken place as formerly, to the great detriment of the trade.

The results of the modern improvements of the Shannon, in a commercial point of view, have not, after some years of trial, answered the expectations formed of the great benefits to be derived from them, any more than the improvement of an older date—shewing what seems manifest enough, that facilities should rather wait on than precede development; and although at some remote future date, and by the introduction of new sources of industry, the commerce of the river may, notwithstanding railway competition, grow by slow degrees up to the accommodation provided for it; yet the incurring of great expense, by anticipation, is wrong in principle as well as unjust to those who have been taxed for the benefit of a future generation, as the proprietors of the border counties have been, to a large amount, by compulsory Grand Jury presentments. But, looking to the nature of the soil, and general character of the country as to productiveness, from lough Allen to Killaloe, there are no strong grounds to anticipate that, under ordinary circumstances, there will be at any future time an adequate return made to the counties for the outlay to which they were subject, although half the cost of the works was contributed out of the public purse.

The total cost of the works was, . .	£510,750	15	9
Paid for property, required for the purposes of the improvement, ...	74,054	2	1
	£584,804	17	10

The half of the above, with the exception of a small portion paid out of the produce of the tolls, was levied off the neighbouring counties.

The land relieved by the operations of the Commissioners is stated in their 11th report to be 18,750 acres, which, it is to be presumed, includes the portions subject to temporary flooding during a period of from three to six weeks, instead of as formerly for nearly as many months.

The fishery of the Shannon, placed under the control of the Board of Works by the act of the 5th and 6th Vict., cap. 105, in 1842, is not the least productive trade of the river, giving satisfactory proof that the contrivances for the passage of fish (consisting of oblique steps, or a zigzag in the slopes of the weirs) have perfectly answered the intended purpose.

Adding to the amount above stated, the sum of £325,873, the cost of the improvements made between the years 1755 and 1812, as already described under the heads of Limerick and Upper Shannon navigations, there appears to have been expended, at different times, within a period of 100 years, the enormous sum of £910,677 on the improvement of this river, which presents, with its series of extensive lakes or reservoirs, connected by deep channels, conditions considered favourable for a combined system of drainage and navigation.

ARTERIAL DRAINAGE.

That the drainage of the extensive tracts of flooded lands in Ireland was an object of considerable interest at an earlier

period of the history of the country than the year 1715, when the Drainage and Navigation Act referred to, in treating of the Bog Survey, was passed, is proved by the fact that several instances yet remain of works, of which there is no record, executed for the purpose of opening up the outfalls of important districts. Twenty different extensive schemes of navigation and drainage were contemplated at the period of the passing of the above-mentioned act, but a few only of the former, already described, were undertaken. It appears not unlikely when the drainage of the great level of the Fens, called the Bedford Level, was planned by Vermyden, a Dutch Engineer, in 1640, that attention became directed to matters of a like nature in this country also, where the resources for carrying them out to any useful extent did not exist.

With the exception of the Bog Survey of 1809, no new drainage measure but Rennie's project for lowering the waters of the Shannon were contemplated until 1831, when a step of intended importance was taken in passing the 1 & 2 Wm. IV., cap. 57, commonly called More O'Ferrall's Act, amended and extended by the 5 and 6 Vic., cap. 105, the principal of which was to execute arterial drainage by local agency; it was, in fact, an extension to Ireland of the private drainage acts of England, the difference being that the latter were strictly local, whereas this was a general act on the same principle, enabling individuals to combine for the execution of particular projects, with consent of the Lord Lieutenant, and to form corporations for the specific object, with power to raise money on debentures to execute the works, and, after completion, to provide for keeping them in repair; also for levying a rate for that purpose from the proprietors interested.

This act was brought into very partial operation in two instances, of which one only was by the foundation of a company for the drainage of lough Corrib, a scheme rendered abortive by the subscription not filling; the work was, how-

ever, undertaken some years subsequently on a more comprehensive plan by the Board of Works. The other instance refered to went no further than a preliminary survey of the river Blackwater in connexion with Mr. More O'Ferrall's property in the county of Kildare, he was, however unable to induce his neighbours to combine with him, and the project fell to the ground, but was afterwards carried into execution under the provisions of the 5 and 6 Vic., cap. 89. There were also one or two minor drainages executed by Grand Jury presentment in the manner prescribed by the act of 1831, which finally became inoperative from the unwillingness of the parties interested to co-operate under its provisions in the absence of compulsory powers.

The improvement of the Shannon, and the drainage of the great tract of adjoining lands already described, were the next projects undertaken, the primary object having been navigation with a secondary view to drainage, the scheme was, therefore, founded on a compromise between those two objects, not altogether favourable in the execution to the latter, the combination of both presenting a difficulty which was not provided against by a sufficient capacity of channel, or a means of regulating the discharge of the weirs; the aim was, however, in the right direction, so far as indicating the true principle—namely, that the measure of the first importance should be the opening of the channels of the rivers which are the main outfalls of the drainage of the country.

The acts 1 and 2 Wm. IV., c. 59, amended by 5 and 6 Vic., c. 105, above referred to, having produced no practical result, the 5 and 6 Vic., c. 89 became law in 1842, and the arterial drainage was placed in the hands of the Board of Works. Under this act any person interested in the drainage of lands, and the opening of any navigation in connexion therewith, might make application to the Commissioners to have its provisions applied, upon his undertaking to pay the whole of the

preliminary expenses in case the project should not be approved of, but if, on taking the necessary steps to enable a judgment to be formed, the Board of Works decided on the propriety of proceeding in the matter, the preliminary provisions of the act were put in operation, and the expenses became part of the charge upon the lands—reports, plans, surveys, and valuations were lodged for inspection—a preliminary meeting was held in order to afford an opportunity for discussion, and, on the opinions of the proprietors appearing to be generally favourable, forms of assent were issued, and, if the owners of two-thirds of the land to be drained—subsequently altered to one-half of the land—concurred, the Commissioners issued their declaration accordingly, appending a schedule of the lands for which the assents had been received. This declaration was lodged for 21 days to afford an opportunity to parties interested to enter objections, but, if no objections were made, or if made, were found invalid, the Commissioners issued their final notice, that all the requirements of the acts had been complied with, and then the works were commenced.

It was originally contemplated to execute the works by funds borrowed by the Board of Works from pivate parties on debentures, or from the Government, the latter, however, with very few exceptions, proved to be the only available resource. On the completion of each undertaking, the valuation was revised, and the expense apportioned on the lands drained, according to the benefit conferred, after which the final award of the Commissioners was made, the number of years fixed for the repayment of the cost of the works by half-yearly instalments, and Trustees appointed, to whom the district was handed over for maintenance, whereupon the powers of the Commissioners of Drainage ceased.

The works executed by the department, in the first instance, having been deliberately entered into, and carefully carried out, under ordinarily favourable circumstance, were attended

with success, and gave much general satisfaction, but, under the provisions of the 9 Vic., cap. 4, commonly known as the Provision for Summary Proceedings, many of the requirements of the former act were dispensed with to enable works to be more speedily commenced, to meet the demand for labour, and to relieve the burthen of the poor rates during the pressure of the famine of 1846 and 1847.

One of the serious difficulties met with at the commencement of the works of drainage in Ireland, under the more recent legislative enactments, was to ascertain with any degree of accuracy the actual amount of flood or drainage water to be dealt with. The quantity of water which falls on the surface of the earth in the form of rain, and the proportion delivered into the river channels to be conveyed to the sea are not absolutely known in any country, and with us these inquiries are in their infancy. It is but lately that observations of the quantity of rain falling in Ireland have been made with regularity at any considerable number of points. In the year 1844, just about the time when the surveys and inquiries for the first drainage district, under the late acts were being made, Sir Robert Kane published his *Industrial Resources of Ireland*, in which he enumerates only five places where observations of the rain-fall over a number of years had been made—namely, at Dublin, Belfast, Cork, Castlecomer, and Derry. Four of these places being situate on the eastern coast, and only one in the interior of the country, but on the western coast, there is no place mentioned where continued observations had been made. To these, however, may be added Markree Observatory, near Sligo, on the western coast, and Armagh and Florence Court, near Enniskillen, in the interior of the northern part of the country.

These registries may be sufficient for general philosophical purposes, or for arriving at general conclusions, but they furnish very imperfect data to the practical engineer in

designing works of drainage, for, however useful they may be as guides to the quantity of rain falling within the basins in which they are situated, they are of but little practical utility in other catchments differently circumstanced as to physical features, and meteorological influences, there being no reliable means of judging by analogy from one basin to another.

The only allusion made to the subject in the Bog Reports is the statement that the annual rain-fall may be taken at 30 inches, the evaporation from the surface of water, 36 inches, and from moist earth covered with grass, 25 inches; and, as it is not stated that these data are derived from actual observation, there is reason to believe that the amount of annual evaporation was copied from the experiments of Dr. Dalton, at Manchester. It is stated by Mr. Nimmo, in the Report dated the 27th December, 1811, that the quantity of water delivered in moderate rains is about one cubic foot per second for every 100 Irish acres, and that winter floods give about three or four times that quantity. This latter statement although vague is much more practical than the former, but the data upon which he came to this conclusion are not given. Rain gauges on the eastern sea-board would be bad indices of the quantity of rain falling in Connemara, Mayo, and Sligo; as, for example, the rain registered at Ardee, county Louth, was, in 1850, 20·30 inches; at Maam, county Galway, 77·54 inches; at Castlebar, county Mayo, 37·55 inches; and at Markree Observatory, county Sligo, 37·179 inches. Ireland being exposed to the direct influence of the Atlantic Ocean, a vast amount of moisture is carried to it by the prevailing southerly and westerly winds, and, although there is probably not more actual rain than in England, there is unquestionably more humidity. On an average, half as much more rain falls in these Islands than falls on the Continent of Europe, and the humidity here being greatly in excess, no experiments made on evaporation in continental countries can be properly made

to apply. But, supposing, however, that reliable observations had been made on the rain-fall, absorbtion, and evaporation in the several seasons of the year, in this country, such information would be much too general, and by no means adapted to furnish data for calculating the proper capacity of the river channels with the available declivity for carrying off the maximum floods at the proposed levels.

The foregoing brief remarks will give some idea of the prevailing want of information, and the perplexities with which the practical Engineer was beset when he entered on an inquiry into the circumstances of a district, with a view to devise plans for its drainage. In many instances the surveys were made in the dry season, when the only means for ascertaining the quantity of flood water to be discharged in a given time, were certain local marks of the level to which the water rose when the floods were at their greatest height. On this subject Mr. Mulvany stated, in his examination before the Select Committee of the House of Commons, in 1852, that the information then arrived at upon accumulated facts was, that quantities of rain-fall, varying from half a cubic foot per minute per acre of catchment basin to 13 cubic feet per minute per acre, had to be discharged.

The total number of districts in which works have been executed amounts to 121. They may be divided into three classes—1st, simple drainage districts; 2nd, slob lands embanked from the sea; and 3rd, districts in which drainage and navigation are combined. Of the whole number, 103 were undertaken under the provisions for summary proceedings, of the Act 9 Vic., cap. 4. The number of districts coming under the denomination of simple drainage cases, is 110, ranging in extent from 88 statute acres of land, drained and improved at an estimated cost of £244, to 29,597 acres, at a cost of £158,423. The features generally presented were a succession of flat lands, separated from each other by shoals

or barriers, forming the principal obstacles to successful drainage and improvement. The river channels, which were the main drains of these flats, were in the most neglected state, but their partial improvement alone would have conferred a very trifling benefit, unless the out-falls had been opened up. This was the fundamental principle upon which the legislative enactments were wisely based; for, with but few exceptions, the obstacles presented by these natural barriers or shoals to the drainage and improvement of the lands, were greatly increased by bridges, corn and flour mills, and a variety of appliances for fishing erected upon them; and nothing but legislative enactments, conferring ample powers to deal with such erections, could meet the circumstances of the various cases.

When the quantity of flood or drainage water to be dealt with was, as far as possible, ascertained, and plans fixed upon for the remodelling or removal of the impeding erections referred to, the capacity of the river channels or drains became a mere matter of calculation. The principle upon which the calculations relative to the capacity and form of the channels were based, was that generally received and applied in practice, namely, that the theoretic velocity of the water in a channel of symetrical form is a mean proportional between the hydraulic mean depth and twice the sine of the angle of declivity or slope of the water's surface.

Whenever a sufficiency of time was available for reliable observations being made of the quantity of surplus rain or drainage water to be carried off, and where the principle above stated was strictly carried out, the works have been as successful as could have been anticipated; and where otherwise, the cause must be looked for in some interference with that principle, or in a deficiency of pecuniary means, not permitting more than a partial measure of relief.

A great change of opinion took place in the department

after the works were commenced, respecting the depth to which the drains should be sunk. When a considerable number of the first districts were undertaken, the plans were formed on what is now called the shallow system, but extensive alterations became requisite to meet that which was subsequently introduced, and is now known as the deep system, adopted with the view, as far as practicable, of carrying off the whole of the floods within the channels. This departure from the plans made a most material increase in the quantity of work to be done, with a disproportionate increase in the cost, owing to the circumstance that much of the increased depth of channel proved to be rock excavation. There is still a difference of opinion relative to the merits of the two systems,—the proprietors holding that works adequate to protect against ordinary floods, would have been sufficient; while the Department maintained that it would not be possible to fix the capacity of a channel which would just accomplish the object of allowing the lands to be occasionally flooded in the winter season, and prevent such an occurrence in summer, when it would do harm.

These differences gave rise, in many instances, to the suspension of the works, the proprietors having refused to give their assents for further expenditure when the limit of £3 per acre had been reached. Matters remained in this unsatisfactory state for a considerable time, during which much injury was sustained by the unfinished works, and the labouring population became so reduced by emigration and death, that wages had considerably increased. Under this altered state of things, Commissioners were appointed in 1852, to enquire into the operation of the Acts relating to Arterial Drainage in Ireland; and after minute investigation, they reported that a subordinate Board, having had conferred upon it, under the Summary Proceedings Act, powers which it was called on to exercise under circumstances of extraordinary

emergency, ought not to be held responsible for results, and should be relieved from the consequences by those who imposed the duties upon them. The Commissioners were also of opinion that too much had been aimed at, by the Department, in embracing navigation and the embanking of mud lands, and the improvement of mill power with drainage, and that a four-feet clear drainage, at all seasons, might not have been generally substituted in the low lands for the original plans, which were principally designed with a view of carrying off ordinary winter and autumn floods only.

Having taken the whole of the peculiar circumstances into consideration, and seeing that the object of the proprietors was as much to provide food for the starving population around them as to increase the value of their property,—the emergency having been such, from May to October, 1846, no less than 101 districts were surveyed, plans and estimates prepared, and the works commenced,—the Commissioners came to the conclusion that the only just settlement would be to limit the contributions of the landowners to the original estimates of cost, with interest in each case, up to the period when the works were suspended for second assents, and to complete the undertakings at the charge of the public exchequer.

This recommendation was carried into effect, and in many cases in which the second assents had been given, and the accounts closed, the awards were opened and readjusted on the principle recommended by the Parliamentary Commissioners.

Few of these drainage districts presented what may be called engineering difficulties, and such as did occur were principally connected with turloughs and bogs. Turloughs are tracts of flat land which are converted into temporary lakes in flood time, there being no sufficient outlet through the fissures of the subjacent cavernous rock.

The outfall of the Turloughmore drainage district, in the county of Galway, is a channel cut through limestone rock, about 25 feet deep, and a mile and a-quarter in length; and the out-fall of the Mantua turloughs, in the county of Roscommon, was made through a very deep bog, principally by a system of surface drainage and tapping. In some instances deep cuttings through rock, to relieve valuable turloughs, as in the Mask and Robe districts, were arched over, and the spoil deposited thereon to reduce the cost of land purchased for the purposes of the works.

The undertakings for the embankment of slob lands from the sea were six in number, namely:—Ballyteigue, Kilmannick, Clonakilty, Youghall, Shandon, and Cork. The works were not accompanied by any extraordinary difficulties. The system adopted was simply to intercept the drainage-water of the adjacent uplands, by contour catchwater drains discharging beyond the extremities of the embankments formed for enclosing the reclaimed lands; and self-acting valve-sluices were constructed in the embankments, at or below the level of low water of spring tides, for the passage of the water.

The districts in which navigation was connected with drainage were originally five in number, of these, however, two only—namely, lough Neagh and Ballinamore, of which Ballyconnell forms a part, were executed as designed. Loughs Corrib, Mask, and Carra were partially executed as a joint scheme, the navigation being completed from the sea to Cong; and from the latter place to Ballinrobe, for drainage purposes only. The works of loughs Oughter, Gowna, and the river Erne were confined to drainage purposes, as were also those of the river Hind, in Roscommon.

Local circumstances afforded great facilities for the execution of the combined works. The valleys, as already stated, in which the rivers flow are generally divided into extensive flats, separated by shoals, or hard barriers, affording very

desirable sites for navigation locks, to overcome the ascents with the existence of many extensive deep lakes, yielding an ample supply of water for the efficient working of the navigation. It was long considered impracticable to combine navigation and drainage in one measure, so as to arrive at ultimate success in both, but, although difficult and expensive of accomplishment, it ought not to be looked on as impracticable. No doubt, there have been failures, but in such cases it might not be difficult to shew that undue preponderance had been given to one over the other, or the efficiency of the one sacrificed for the other, according to whichever might be most popular, or apparently most promising at the time; but in a well-arranged design, where each has its due share of attention, there is no incompatibility, and the two objects may be made so as mutually to aid each other and secure the success of both. Few countries afford so many natural facilities for an extensive and highly beneficial system of inland navigation and drainage as Ireland, and, no doubt, if the subject had been better understood, advantage would have been taken of them to a much greater extent, and in a more effectual manner, than has yet been done.

The first drainage and navigation district in the order of time is that of Ballinamore and Ballyconnell, extending from the Shannon, at the town of Leitrim, to lough Erne, near Crom Castle.

With reference to the history of this project, it appears from the Journals of the House of Commons that, about the year 1780, the works of a proposed navigation from lough Erne to Woodford lake were commenced. In 1786 Mr. Richard Evans, who had been originally employed to lay out the course of the canal, and had agreed with contractors for its execution, was called on by the Commissioners of Inland Navigation to make an inspection with reference to the expenditure of a sum of £1,000, granted in the Session of 1783–4.

He reported that he found a great part of the canal excavated —one lot not touched—others not sunk to a proper depth—the lock at Carrowl two-thirds built, and nearly as much cut stone on the ground as would complete it—the lock-house built, and the gates of the lock framed, and made of excellent materials; however, notwithstanding the progress made, the undertaking was not prosecuted.

In 1778 Mr. Evans also gave plans and an estimate for "the construction of locks, and cutting a complete canal from the harbour at Ballyshannon (at Murray's-quay), through Ballinacarrick, Cherrymount and Crumlin, there to cross the river Erne by an aqueduct-bridge of two arches, and through the town of Belleek to the navigable part of lough Erne, above the falls."

Of this project a portion of the canal between Belleek and Ballyshannon was excavated, and the regulating or guard lock at the the former place built; but, although this undertaking, as well as that of the Woodford river, were very favourably reported on by Mr. William Chapman, both were abandoned for the same reason—namely, want of funds—before the year 1794, about which period that distinguished engineer left Ireland for his native country.

Mr. Evans's estimate for the canal from Ballyshannon to the lough Erne, above the falls, was £32,208 19s., and to render the lake navigable from the falls and thence to Enniskillen and Belturbet, and from the upper lake to Ballyconnell, £7,791 1s., making together a sum of £40,000 for a navigation of 61 miles. This was intended to form part of a great national inland communication; its proposed future extension to be from Ballyconnell, by the Woodford river, to Ballymore and lough Scurr, and to the Shannon, at Leitrim.

Attention having been again directed, in the year 1800, to these projects, Mr. Evans was called on to submit to the Board of Inland Navigation a revised estimate, to which he added a

sum of £8,000 on account of the increased price of labour; but the sum of £500,000, granted by the English Parliament for the completion of the unfinished works generally throughout the country, having proved wholly inadequate for that purpose, these, like many other undertakings, were put aside to make way for more urgent claims upon the grant.

The proposal for effecting the junction of lough Erne with the sea was renewed in 1812, when Mr. Kilally surveyed a line of canal from the lough to Ballyshannon; the estimate of that work, independently of any improvement of the harbour, amounted to £63,000. Mr. Kilally having been again called on in 1831, confirmed his views of the expense; the only line through which such a work was practicable being through limestone rock, with a thin alluvial cover very near the surface.

In 1832, Messrs. Robert and Allan Stephenson, having been called on, considered that the deepening of the harbour of Ballyshannon should take the lead of every other work, and with that view they gave a plan and estimate for the removal of the bar, consisting entirely of rock, and presenting much difficulty, owing to the strength of the current, which runs on the one hand from the basin of the harbour, and on the other from the surge of the ocean. The amount of the estimate was £5,561. These engineers, having seen that a canal could not be made, except at a great expense, proposed, instead of it, a road 5 miles in length, commencing at the harbour, and passing, by means of a tunnel or bridge, under the principal street of Ballyshannon, and terminating at the quay of Beleek, on lough Erne; this road being laid out on a very easy line of draft could be converted into a track for a railway. The estimated cost of the road was £18,133, and, if afterwards converted into a double line of railway, the additional cost would be £10,641.

No further attention appears to have been directed to any

of the projects in this locality until 1838, when the Shannon Commissioners were called upon by the Lords of Her Majesty's Treasury to report on the practicability of making a canal between the Shannon and lough Erne, and, accordingly, a line of still water navigation was surveyed, and an outline of the proposed plan laid before them, by Mr. W. T. Mulvany. This survey led to no practical result at that period. However, on the passing of the Act 5 and 6 Vic., cap. 89, the Ulster Canal Company, with the view of obtaining a connexion between their navigation and the Shannon, applied to the Commissioners, and agreed to meet the expenses of an engineering enquiry, which was made in the years 1844 and 1845, and all the preliminary requirements of the Act having been complied with, the works of the combined plan were commenced in the summer of 1846. The length of the navigation is 40 miles, passing the towns of Ballyconnell, in the County of Cavan, and Ballinamore in the County of Leitrim. In the whole distance there are 25 miles of the Woodford river made navigable, 10 miles of lakes, and 5 miles of artificial cuts. The locks, of which there are 8, on each side of the summit, are 82 feet long in the chamber, 16 feet 6 inches wide between the uprights, with 5 feet 6 inches water on the sills. The whole rise, from lough Erne to the summit level, is 66 feet; and from the Shannon, in the ordinary state of the summer water, to the same point about 77 feet.

The locks are built of first class rubble masonry, strengthened with cut-stone bonds, the sills, breasts, hollow quoins, and coping are of cut stone; the gates are framed of red pine timber, and opened and shut by swing beams in the usual manner. The lifts of the locks are not uniform, varying from 5 to 12 feet to suit the inclinations of the ground. The levels of the respective reaches are maintained by regulating weirs of variable length, according to the quantity of water to be discharged within a rise of two feet, except in one instance, at

the outfall of the lower assemblage of lakes, where the range is 3 feet. The artificial cuts and those portions of the river channel where the discharge of the drainage water could not be effected with a less sectional area, have a 22 feet breadth of bottom, 9 feet depth, and slopes from 1 to 1½ to 1.

This navigation was considered of much importance, as it forms the connecting link between the northern and all the other inland navigations in Ireland, but having been opened only in 1860, there has not yet been sufficient time for the development of the expected traffic. The expenditure, not including interest, was £167,578.

The next in order of time was the lough Neagh drainage and navigation district, there are evidences still existing of the attention of the landed proprietors having been directed at a very early period to the drainage of the lough, so as to prevent the recurrence of the injuries to which the lands, under its influence, were exposed, from its annual overflowing; but at what time the navigation of the lower Bann, which flows out of it, was proposed appears not to be now known. The first recorded notice of such a project is in the Statistical Survey of Armagh, by Sir Charles Coote, drawn up about the year 1802; two canals, or navigations, had been previously opened into the lough, namely the Lagan Navigation, completed in 1793, and the Newry Navigation, opened in 1768, as already noticed.

The first complete Engineering project, for making the lower Bann navigable, was submitted to the Commissioners of Bog Improvement by Thomas Townsend, and printed, by order of the House of Commons, in 1814. Between that date and 1844, various plans were put forward by the prominent Engineers of the day, namely, by Alexander Nimmo in 1822; Sir John Macneill, in 1836; Thomas Rhodes, in 1839; and Francis Giles, of London, in 1843.

In the year 1844 the proprietors of the lands around the

lake applied, by memorial, to the Commissioners appointed under the 5 & 6 Vic., cap. 89, for an inquiry to be made, and for a survey and plans, with a view to the improvement of the drainage and navigation of the lough and the lower Bann river. The survey was made in 1844 and 1845, the report and plans were submitted to the Commissioners in December of the latter year, and the preliminary proceedings required under the Act, having been completed, the works were commenced in May, 1847.

The lower Bann, as remarked by Mr. Townsend in his report, is formed by nature for a navigable river, not being one gradual descent, but in level reaches, the fords, or falls, are short and few in number, so that with the aid of a few locks at those places, the materials for which are on the spot, the river immediately becomes navigable. A very serious mistake was committed at the commencement of the inquiry. the out-fall of the district was fixed at the Cutts near Coleraine, by which the remaining portion of the river, from that place to the sea, as well as the port of Coleraine were excluded from the plan of improvement. What renders this the more anomalous is that the locks and bridges are constructed for the passage of masted coasting vessels, and yet the entrance to the navigation is inaccessible to such craft, as there is no provision for their passing the bridge at Coleraine. This portion of the lower Bann formed the subject of a separate inquiry, but as there were no flooded lands, and, consequently, no drainage, the proposed works could not be undertaken under the provisions of the 5th & 6th Vict., c. 89.

The distance from the out-fall at the Cutts, near Coleraine, to the lough is 32 statute miles, and the rise from the level of low water of spring tides to the regulated summer level in the lough is 46 feet. That ascent is overcome by four single and one double lock, with side cuts and regulating weirs. The locks are 130 feet long in the chamber, 20

feet wide between the uprights, with 8 feet of water on the sills.

The extent of the shores of the lough, gives ready access to a large extent of surrounding country, and its connexion with the Lagan, Newry, Coal Island, and Ulster Canals, affords means of communication with all the inland navigations of Ireland.

The area of the lands drained and improved was 29,597 statute acres, at a cost of £158,423. Of this, a sum of £8,513 was presented to be paid by the counties of Antrim and Londonderry, for certain works chargeable to these counties, leaving the sum of £149,909; but under the provisions of the Act, 17 Vic., the Lords of the Treasury remitted the sum of £39,909, thus reducing the liability of the landed proprietors to a sum of £110,000, payable in 44 equal half-yearly instalments of principal, and interest at 4 per cent. The original annual value of land drained and improved was £25,635, and the increased annual value, £9,879.

The lough Corrib drainage and navigation district was surveyed in 1844 and 1845, and the Reports and Plans were submitted to the Commissioners in March, 1846. This district, originally included loughs Mask and Carra, but these were subsequently carried into effect as drainage measures only, and the navigation limited to lough Corrib and its connexion with the sea at Galway, there having been a want of funds to complete the undertaking; but there was a considerable sum expended to no purpose in rock excavation and the erection of locks between loughs Corrib and Mask.

It is on record, that an attempt was made, in the year 1498, to connect lough Corrib with the sea at lough Athalia, by a canal following the course of the Terryland river. The remains of this effort, which are still extant, show that the project, though feasible, was not completed.

In the year 1822, the late Mr. Alexander Nimmo, gave a design for a canal to extend from lough Corrib, at the Wood Quay, to a floating basin, proposed by him to be supplied with fresh water, at a higher level than neap tides; but as injury would be done by that means to property in the lower part of the town, the project was abandoned. In the year 1830, Mr. John Kilally, Engineer to the Directors-General of Inland Navigation, having been called on, in conjunction with his son, Mr. Hamilton Kilally, designs were given for the floating dock, as now built, the water of neap tides only being penned, and the sill of the lock-gates being placed 5 feet below the low water of ordinary spring tides. No connexion was made between lough Corrib and this dock, which was constructed for the accommodation of shipping, and was unsuited for the reception of the very large number of sea-going small craft engaged in fishing and agricultural traffic.

The canal, which has been constructed for the connexion of lough Corrib with the sea, named the Eglinton Canal, leaves the tideway of the river Corrib on the west side of the entrance of the new floating dock.

A large tide basin has been constructed to facilitate the ingress and egress of vessels. This basin is entered by a lock with a lift of 7 feet, the lower sill being placed 5 feet 6 inches under low water of neap tides, so that vessels drawing 6½ feet water can enter on the first quarter of flood, and rise to a height of 13½ feet over low water, being the level of the floating basin, which communicates with a double lock, with lifts equal to 13 feet 8½ inches, in order to raise boats to the level of lough Corrib. The locks are 130 feet in length from cove to cove, and 20 feet 6 inches in breadth between the quoins. The canal sweeps round from this lock for more than a quarter of a mile in length and enters the western branch of the river, near the new College.

The principal thoroughfares are carried over the canal by

wrought iron turning bridges of a new construction, being in one leaf, the design of Mr. Mallet. The navigation from the new College to lough Corrib is by the river channel and what is called the Friar's Cut. Wharves have been built for the accommodation of the trade at several important points on the shores of the lough, and beacons and buoys placed to point out the deep sailing channel.

The whole expenditure on the different undertakings under the Arterial Drainage Acts, including £70,201 for works chargeable to counties, amounted, at the end of 1858, to £2,342,746, with interest; of this total, £1,099,001 was expended on the completed districts, and £1,243,745 on districts not then closed. The area of the flooded or injured lands drained and improved in the completed districts, is 175,443 acres; and of the above sum of £1,099,001, expended for that purpose, £485,869 has been remitted, £47,781 2s. 1d. charged to counties for public works, and £565,977 charged on lands; making an average cost to the proprietors, including interest, of £5 19s. 11d. per acre, the increase of the annual value being estimated at £49,060 10s. 9d. Whether the improvements are worth, on an average, an increased value of six shillings per acre, the annual interest at 5 per cent. on the expenditure, remains to be determined by the proprietors, who have the power of raising the rents of the lands, or of turning them to profitable account, if in their own possession.

Notwithstanding that a quantity of land, amounting to about 330,000 acres, has been permanently relieved and improved, under the Drainage Commission, and nearly 20,000 acres freed from all but temporary floods by the Shannon improvement, there are yet numerous and extensive tracts requiring to be drained, many of which were not undertaken by the Department, and some abandoned from want of means of carrying them out; and as successive Governments, unwilling to continue the legislation intended for the emergency

of the famine, have refused to enter into any new projects under the existing Acts of Parliament, which are consequently rendered a dead letter, there is a want of such well-considered legislation as, with the ample experience of the past, would enable proprietors to have works of that description performed in a beneficial manner under their own control. And as this leads us again to the consideration of the question of the difference between the Department and the proprietors, as to the principles on which drainages should be regulated, it appears sufficiently manifest that every district has physical features peculiar to itself, that no perfectly uniform system ought to be adopted—occasional sinking and embanking, with such back drains as circumstances would point out, and taking advantage of the readiest out-fall—being the only obvious general rules for guidance which can be laid down, together with provision for a previous apportionment of the cost to each proprietor, founded on a careful estimate of the facilities or difficulties of each particular locality, so that the smallest effective cost of the benefit proposed to be conferred should be known before hand, and assented to, it being understood that an average of the cost per acre of the land to be drained would, for obvious reasons, not be a proper basis of apportionment; nor would a principle of complete isolation of each district answer, for if the whole course of a river is to be drained, considerable expense would be thrown on the basin lands in providing against flooding by the more rapid flow of water from the districts above them, where the quantity of land drained would be comparatively small. Then, again, there are low lying lands, requiring, for their relief, measures of an extent not caused by the necessity of carrying off the waters flowing from the districts above them. In such cases it is clear that a different mode of apportionment should be applied. It will thus be seen that there are a great variety of matters to be considered in legislating anew on this important subject,

and the least difficulty will certainly not be the appointment of a tribunal to value the improvements and apportion the cost in a manner satisfactory to the landed proprietors, as well as to provide for the proper maintenance of the works.

WATER-WHEELS.

We are indebted to the Romans for the introduction of the water mill into the British Islands, the quern having been the only contrivance for grinding previously in use. A specimen of a very early water-wheel is preserved in the collection of the Irish Royal Academy, it consists of a solid disk of timber fixed on a vertical shaft, the edge of the disk having diagonal floats morticed upon it; the jet of water was delivered from above by a shoot. This rude form of machine is in some rare instances still in use amongst people of Celtic origin. Up to 1807 wood was exclusively used in Ireland for mill machinery, but in that year metal gearing was applied in a large mill erected by Mr. Wye Williams in Belfast, on the introduction by him of a new process called beetling and finishing of linens.

A form of improved over-shot water-wheel, of which there were two varieties, partly of iron and partly of wood, commenced to be pretty generally used in Ireland about the year 1820, of these, one description consisted of cast-iron shaft, grasps and shrouds, all the rest being of timber; the other having in addition, plate-iron sole and buckets, and timber arms. The earlier attempts at improved wheels had the shafts only of cast-iron. Amongst the first and most successful Engineers in the adaptation of wheels of the compound description were the Messrs. Mallet, who erected a very large number of them in the counties of Dublin and Wicklow, varying in size from 40 to 60 feet diameter, and 6 feet in the buckets, for the various purposes of corn-milling, linen, cotton, and

woollen works, flax scutching, and spinning, paper-making, and raising water. The corn mills were furnished with machinery for moving and distributing the grain, from its entrance to its delivery as flour, into sacks, without manual labour. Many excellent examples of the above class of wheels were, also, about the same period, erected by Messrs. Steel and Hopkins, of Cork; Roberts, of Mountmellick, and Murphy, of Wexford.

The largest, and one of the best examples of the compound over-shot water-wheel is that of Mr. M'Donnell's paper-mill at Saggart, it is 80 feet in diameter, and 8 feet width in the buckets, and was originally attempted to be constructed wholly of iron, but having been miscalculated as to strength and design was always troublesome to keep in order, and at length it broke down in 1848, when the Messrs. Mallett were employed to reconstruct it. They removed the whole interior of the wheel, shoring up in true form the huge plate-iron ring, and then inserting within it new shaft, grasps, and oak arms, with circular staging connected with spur segments, taking off the power and wrought-iron diagonals across the breadth. The working has since been quite satisfactory.

The first water-wheel made completely of iron was brought into the North of Ireland in the year 1829, for the Earl of Caledon, by Fairbairn, the satisfactory character of whose work procured him similar employment in different parts of the country, but wheels wholly of iron have been considered too costly, the compound over-shot wheel has, therefore, prevailed, being more suited to the amount of capital usually invested.

The turbine, or horizontal wheel, invented by M. Fourneyron, was introduced into this country in 1846, by a millwright of Armagh, named Gardiner, who erected some of them in the North. Its true applicability is limited to very high falls with small volume of water, or to very low falls

(under 8 feet), and liable to serious backwater, by which it is very little effected; in all other cases, the well-made over-shot wheel gives as large a return in "work," is far more stable and enduring, and is, on the whole, less costly. An instance of the applicability of the former may be mentioned. On the river Inny, near Ballymahon, Mr. Mallet constructed—some 10 years since, on a fall of 7 feet—a large turbine, which receives a great volume of the river (nearly 500 cubic feet per second). In winter the average fall is reduced to about 5 feet, and in floods to 3 feet. It drives a flax steeping and scutching establishment, with spare power for a corn mill; it is peculiar and original in some points of construction. The diameter of the revolving ring of buckets is about 8 feet. The whole of the moving parts, though held steadily by a bottom pivot, are supported from above at the top of the vertical shaft by a ring of revolving conical rollers, like the top leaf of a swivel-bridge, so as to obviate the difficulty of access for oiling and cleaning the bottom pivot, as well as the evil of excessive wear from the enormous load usually imposed upon it, amounting to the weight of the machine, with the whole water pressure upon the revolving disk, being in this instance 7 feet head on a circle of 8 feet diameter. This machine continues to work well, and when put up showed on dynamometric trials a power of about 76 per cent. of the fall in the highest backwater. On the same river, at Ballymahon, Mr. Mallet constructed a corn-mill of six pair of stones on Poncelet's reactive system, as far as timber buckets would admit. It has been found to work well, and is, probably, the only one of that description in Ireland. The water-wheel is a low breast one, the fall not exceeding six or seven feet at most.

Mr. J. Thompson, C.E., of Belfast, the brother of the Professor of the same name, is the inventor and patentee of a form of turbine, which he designates the vortex wheel, differing from most other turbines in receiving the water at

the periphery, and delivering it at the centre of the revolving portion. He has erected several of these with successful results. At Colooney, in the county of Sligo, the Messrs. Randolph, of Glasgow, erected, for Mr. Sims, a turbine on Whitelaw and Stirrit's principle, the arms, however, are enclosed in a cast-iron box. The wheel is 9 feet diameter, and 1 foot 4 inches thick. The fall 30 feet, and the water is delivered beneath in a cast-iron pipe 2 feet 6 inches diameter. There are 3 apertures of issue, each $2\frac{1}{4}$ inches wide. This wheel works 14 pairs of stones in a very satisfactory manner, and was calculated for 22 pair.

Much has been said and written on our great natural source of wealth by means of water-power still remaining unappropriated, but it is not enough to prove that so many thousands of horse-power are running to waste daily in various localities, it being far more important to show how a market can be procured for something that the power will make; many circumstances besides the mere money question of cost of power against carriage are opposed to the raw material being brought to the cheap power, and the manufactured article from thence to the distant market. Portlaw appears to be one example of the contrary, but it is wholly exceptional. On the other hand, the north of Ireland, and more especially the district of the Upper Bann, present the true conditions for the fullest realization of water-power, where the manufacture, the market, and the power are all on the spot. When these conditions are far apart it will often be better to employ the dearer steam-power near the market than the cheap water-power at a considerable distance from it. What Ireland requires is, that some branch of manufacture should be added to agricultural pursuits, as we find to be done with success in the north, where markets are established for the sale of skutched flax and yarns from the hands of the farmer, who thus gets his share of the profit at an early stage of the manufacture, and is thus repayed for

his flax crop, which, from its exhaustive nature, would not otherwise be remunerative.

In connection with the history of a minor branch of hydraulic Engineering in Ireland, it is right to notice the introduction and improvement of the hydraulic-ram as an instrument for raising water; up to the year 1827 it remained much in the state described by its inventor, Montgolfier, and was principally known in England as an object for philosophical lecturing, and, described in the Repertory of Arts, a modification of it having been erected by Whitehurst, the eminent clockmaker of Derby; the extraordinary and useless appendage proposed to it by its inventor for getting air back into the air vessel, as it was supposed to be absorbed by the water pumped through, having still remained a supposed essential of its construction.

About the period above mentioned, Mr. Robert Mallet, senior, commenced making the machine from the published description of the inventor, and also on plans of his own, the result of which was that he found the air restoring valve to be quite unnecessary, and that the return in work of the construction on Montgolfier's model was very small compared with the modified plan. In 1831 Mr. R. Mallet, junior, following in the track of his father, brought the construction and proportions of the machine to a high state of permanence, and obtained an efficiency quite as great as has been reached by other methods of elevating water by water-power—say 60 to 70 per cent. on moderate lifts and good falls of 8 to 16 feet. The first hydraulic ram erected in Ireland, was by Mr. Mallet in the archepiscopal residence at Clogher, in the year 1828, the fall is about 14 feet, and to the present time it works efficiently, furnishing the town also with a constant supply, elevated about 130 feet. The construction of the air vessel valve, which is exposed to great concussion, has had complete success, and was due to Mr. Mallet, senior. This machine

is a very peculiar and curious one in its action and theory, and much even yet remains to be done in its useful application. Eytelwein has made experimental investigations of it but without adding anything to its effective operation.

THE STEAM-ENGINE.

IRELAND being little of a mining or manufacturing country, and coal being comparatively dear at the centres of industry, there has been but small demand for machinery, except that worked by water-power, we, consequently, took little or no part in the mechanical inventions and improvements of the last and present centuries connected with steam-power, and this is not to be wondered at, seeing the special character of steam-engine making, the necessity for a great demand to encourage and support it, and the excluding effect in the market of the immense manufactories which had rapidly grown up in England, devoted to its construction, monopolising the trade of its extended application which belongs to modern times; while the date of the great practical improvement in the steam-engine of Savory, and the atmospheric-engine of Newcomen is not more remote than the year 1774, when James Watt completed his single-acting steam-engine, superseding the previous inventions which were little employed, having been inferior in economy and usefulness to most other mechanical agents in use as prime movers.

The first steam-engine brought into Dublin was one made by Bolton and Watt, and was erected in Meath-street brewery in 1791. Others soon followed, these engines had wooden working beams, connecting rods, sun and planet motion, and hand-gear to the lifting valves, being Watt's earliest method. The first engine of the independent construction by Bolton and Watt was put up at James's-gate about the year 1810, and the same engine with an enlarged cylinder put in by

the Messrs. Mallet, was in use recently, and it is believed is working still.

A good description of small, high-pressure engine, with horizontal cylinders working within spheroidal boilers of cast iron, was made in Dublin between 1800 and 1820 by Popplewell, who had his factory in the Liberty. The valve-gear was peculiar, and, by an arrangement of tappets, the full steam pressure was on the piston during the whole length of the stroke. These were known as Trevethick's engines.

The successful practical application by Fulton of Watt's engine to river navigation, to which alone it was considered adapted, did not take place until 1807.

Dawson, an Irishman, has laid claim to having built, in the year 1811, a steam-boat of 50 tons burthen, called the Comet, worked by a high-pressure engine, what is certain, however, is that the same individual in 1813 established a steam-boat on the Thames to ply between Gravesend and London.

The first attempt made to apply steam propulsion to sea-going vessels, appears to have been made by George Dodd, who, in 1813, brought his vessel from the Clyde round to London by steam and sails. The boat was 75 tons burthen, 15 horse-power, with paddle-wheels 9 feet diameter. In 1815 Cooke, of Glasgow, made a voyage from that city to Dublin, and round the Land's End to London, his vessel was propelled by a side lever engine, of 14 horse-power, and was more perfect in construction than any that had preceded it. The engines in general use at that period were on the bell-crank principle. The bell-crank levers, having received the motion directly from the piston, communicated it by a connecting rod and crank to the main shaft, by which the paddle wheels were turned. The engine, there being but one, was placed on one side of the vessel, and the boiler on the other. The boiler, which was of the form proposed, by Smeaton in 1765, had an internal furnace and flue surrounded by the

water. It was not until the year 1814 that Bolton and Watt connected together two engines for navigating purposes. About the time of Cooke's successful voyage Bolton and Watt, Maudesley, Napier, and others, applied themselves to the making of marine engines.

In the year 1818 David Napier may be said to have established the first regular communication between two distant ports, namely Greenock and Belfast, by placing a vessel of 90 tons burthen, with an engine of 30 horse-power on that station. In 1819 Napier built the Talbot, 150 tons, with two engines of 30 horse-power each, which ran during the summer months between Dublin and Holyhead, but was obliged to be laid up in winter. In 1820 steam-packets built, by Manby, with oscillating engines, were introduced on the post office station, between Howth and Holyhead, these were also unable to ply during the Winter.

In 1823 the St. George Company commenced a communication by steam, for passengers, between Liverpool and Dublin, but the undertaking was not successful, owing to the imperfection of the mode of paddle-wheel propulsion. About the same period Mr. Wye Williams, in conjunction with Mr. John Oldham, patented a wheel invented by the latter for the propulsion of steamers, and having, with Mr. Francis Carleton and a few enterprising individuals, subscribed a sum of £24,000, established a steam-packet company to trade between Dublin and Liverpool, being the first attempt of the kind to cross the channel for trading purposes, or that succeeded in plying during the winter. Mr. Williams, in his work on heat and steam, observes that such was the infant state of steam navigation in 1823, that, although a contract was made with the most eminent engineer of the day for the engines, and an equally eminent ship-builder for the hull, neither could be induced to confer on the subject of securing the engines to the timber framing of the ship, each disclaiming any knowledge of, or responsibility for, the duties of the other.

John Oldham, the patentee of the paddle-wheel on the feathering principle, was possessed of very considerable mechanical ability, and was the inventor of various ingenious contrivances for printing the notes of the Bank of Ireland, and of the system of mechanical consecutive numbering adopted in the Bank of England, and subsequently in all railway stations.

Grantham, whose survey of the Shannon has been already mentioned, was the first who introduced steam navigation on that river in the year 1827. He was, however, pushed out of the field by the Inland Steam Navigation Company, established in 1829 under the direction of Mr. Charles Wye Williams, to whose intelligence and enterprise Ireland is indebted for this and many other commercial benefits The vessels of the company were duplicate or twin boats, the paddle working between. This mode of construction, adopted by Symington in 1787, was in use up to a recent period, when the improvement of the Shannon admitted of a larger class of vessels for passengers, and this traffic having been unnaturally stimulated for some half-dozen years by the opposition to the Great Southern Railway Company, carried on by the Midland Railway Company as lessees of the Grand Canal, gave rise to the introduction of a still larger class of vessels plying between Killaloe and Athlone, but the opposition having been put an end to by an amicable arrangement, after the opening of the Tullamore and Athlone Extension, the passenger traffic on the Shannon, in great part, ceased in the last year.

The first attempt to construct marine engines in Dublin was in 1829, they were designed and executed by Mr. Joseph Clarke, foreman of the Ringsend foundry, and were placed in a vessel called the Marchioness Wellesley. Some marine engines were subsequently made in the same establishment, but the manufacture languished for want of support.

About the year 1836, on the occasion of the wreck of one of the Dublin and London Steam Company's vessels, the Royal Tar, on Arklow bank, her engines were rebuilt by the Messrs. Mallet, the serviceable parts being used. They were the largest engines constructed for marine purposes in Dublin, and were remarkable for being nearly the first attempt in Great Britain to adapt steam at high pressure. This was due to Mr. Francis Humphreys, the marine engineer of the Company. The boilers, which were peculiar (6 cylinders superimposed, 2 and 2), were his design. The vessel was worked many years on the Peninsular station. Humphreys having considered himself inadequately remunerated by the Company went to England, where he patented his trunk marine engine with hollow piston rod containing the connecting rod. Several engines on this plan were constructed by him in England. He was also the inventor of the double nossle valve for marine engines, now in common use, but his invention was patented by a person to whom he unsuspectingly described it. He died in 1842, leaving a brother who possesses much of his talent, and is at the head of a well-known firm of marine engineers.

Marine engine making has not made any progress in Dublin since the break up of the Dublin and London Steam Company, for the practice of their successors, the City of Dublin Company has always been to get their repairs (which feed marine engine works) done in Liverpool, but the final blow was given to the trade here by the establishment created for repairs by the British and Irish Steam Company on the North Wall, when they proferred to execute repairs for other steam companies also. This latter interference, by a Company, with the trade, while it destroyed private enterprise, entailed great loss upon themselves, and their concern was finally broken up, leaving Dublin at the present time, with its large fleet of steam traders, with but one establishment where even

repairs can be executed. There are, happily, in other parts of Ireland exceptions to this regretable state of the mechanical engineering trade, as, for instance, in Drogheda, Cork, and Belfast, where ship-building, and marine engine making are carried on with success, and in the former place a locomotive engine factory has existed for some time. In 1851 steam tug-boats were introduced on the Grand Canal, they were 60 feet in length, and in width, 12 feet; boiler, 4 feet 6 inches in diameter, containing 48 tubes of 2½ inches diameter, and 6 feet long; cylinders, 7 inches diameter; length of stroke, 18 inches; and calculated to make 120 strokes per minute; the pressure being 50 lbs. The boat was propelled by two screws, 4 feet pitch, 3 feet in diameter, 2 feet long, placed at each side of the stern post, worked with bevelled gear, and two-fold multiplying power. The principle of construction of the machinery answered well, and was found capable of being stopped, and the motion reversed with great ease, steering stern foremost almost as well as when running forward, advantages essential for canal traffic, and not possessed by the single screw. Loaded with 20 tons, these towed a boat of 50 tons at the rate of 3·26 miles per hour; pressure, 29 lbs.; average number of strokes, 101. The hulls were made at the Ringsend works, and the engines and machinery by Mr. Inshaw, of Birmingham. Sir John Macneill, in reporting on this mode of propulsion, states that the merit of the plans and arrangement of the machinery was due to the officers of the Company, but more particularly to their very intelligent Secretary, Mr. John M'Mullen, for whom the adaptation only is claimed, the honour of the practical application of the Archimedean screw-propeller, being due to the ingenious and ill-requited Francis Petit Smith, who, in 1837, patented this invention so peculiarly adapted to ships of war.

Looking back to the application of steam-power generally, but more particularly to navigation, we find that, besides

the practical difficulty of the invention, it had, like all great innovations, to encounter a large share of prejudice and hostility at the outset, but, although some of those who helped to solve the problem suffered the hard fate which too often waits on genius, yet others realized fortunes, and ample justice has been done to the memories of all in the numerous works in which their labours are recorded. Let us bear in mind that the field of invention and enterprise yet lies open, and fame and rewards are still to be obtained in this department of practical science, for the steam-engine is still a very imperfect machine, as regards the thermic agency by which mechanical effect is produced, not more than 45 per cent. of the theoretical duty due to the fall in temperature between boiler and condenser being realized in the best Cornish engines, whereas in the best water-power machines from 80 to 85 per cent. of the theoretic duty due to the whole fall is obtained.

In 1798 the *duty* of an engine, which is expressed by the number of pounds raised one foot high by the consumption of a bushel of coal, was, in an engine by Bolton and Watt, found to be 27,000,000, this was declared by Watt himself to be perfect, and that further improvement was not to be expected; in 20 years the average duty of the best engine was 40,000,000, and in 20 years more it was upwards of 84,000,000. The combined improvements in the construction of marine engines, and of vessels, has brought the speed attainable, within a very few years, from 10 miles to 20 miles an hour, there is, therefore, no room to doubt that this may yet be exceeded. The mail packets which are to be on the Kingstown and Holyhead station in the next autumn are engaged to perform an average speed of 20 miles an hour in all weathers.

The foregoing brief notice of a few facts connected with the introduction of steam-power generally has been considered not out of place in a paper of this description, as a useful

memento of the comparatively recent great results of practical development in this department of the profession, and of the rapid progress made in keeping pace with the demand, the lapse of three-quarters of a century, after Dr. Watt had displaced empiricism by the triumph of scientific research, having shewn that the progress of mankind itself has followed steadily in the track of his great invention.

M. Cousin has stated that if the geography of a country, its climate, soil, and physical features be given, that the history of the people who inhabit it may be told, not accidentally, but necessarily. Whether this opinion, which estimates at nothing the genius of a nation, be universally true or not, it is certain that a country like ours, rich in its soil, must have a destiny different from one whose wealth is beneath the surface, and that the obvious policy of countries so circumstanced is, that each should take advantage of its position to supply what the other wants. This principle, when extended, tends to make the human race members, as it were, of one great family, affording, by their dependence on each other, the surest guarantees for the peace and progress of the world.

RAILWAYS.

The promoters of public roads in ancient times have been handed down as great public benefactors, and justly so, as without easy means of communication, improvement must stand still, but how much more worthy of admiration are the originators of the railway system, which, beyond all comparison, has done more, in a short period, towards general amelioration than any invention by which it had been preceded —still realizing, and still promising, by its judicious development, the most encouraging results.

Where there is no government interference, the genius and enterprise of the nation, as in these countries, alone deserve

the credit, as they, sometimes, also pay the penalty of that want of due consideration and safe control which might be exercised by a public board not personally interested in the matters subjected to their decision.

A very few words with reference to the first steps taken towards the introduction of the great agent of modern progress may here be admissible, although Ireland cannot claim any credit, except for its early and successful adoption.

The wants of the mining districts of England, but more particularly of the collieries, had early created the necesssity of an easy mode of transport for heavy loads, and for that purpose waggon roads, laid with cast-iron tram-plates, were brought into use about the middle of the last century, by Reynolds, of Colebrook Dale, and shortly after Edgeworth introduced a train of waggons, with cast-iron wheels, drawn by one horse. The ingenuity of Trevethick, whose fame ought not to be allowed to be eclipsed by subsequent improvements on his invention, succeeded in making the first locomotive-engine, which worked on the Merthyr Tydvil Railway, in the year 1804. It produced a volocity of 5 miles an hour, and was capable of drawing a load of 15 tons at that speed, but the unfitness of the cast-iron plate-rails of that period caused it to be abandoned without further attempts at improvement.

The mechanical mind of Trevethick, seeing that adhesion was the principle for producing locomotion, originated the steam carriage on common roads, and he exhibited one in motion in the year 1806, in the neighbourhood of London, the difficulties, however, in the way of practical success, have not been yet entirely overcome, although much attention has been given to the subject, both in England and on the Continent. In this country, Sir James Anderson expended a considerable fortune in abortive attempts at perfecting the invention. Mr. Gurney, a medical doctor of much scientific acquirement, residing in Cornwall, deserves the credit of

having brought this invention nearest to perfection, in 1822, but, owing to the much greater resistance on a stone road, as compared with a railway, and the consequent loss of power in the former case, a general and well-founded opinion prevails that horse-power applied to tramways would be more economical than steam on stone roads. The evidence necessary for forming a judgment on this subject is to be found in the Report of a Committee of the House of Commons, printed in October, 1831.

Improvements in the locomotive engine followed each other in tolerably quick succession from the date of Trevethick's experiment. Most of them having been directed to the prevention of slipping, without any very decided success, until the year 1814, when George Stephenson's engines commenced to be brought into general use on railways, instead of horses for drawing coals, and, in 1816, the introduction of the cast-iron edge-rail, and flanged wheels, in place of tram-plates, was soon followed by wrought-iron rails, formed of rolled bars. Improvements were thus gradually worked out, principally at Newcastle, until a speed of 8 miles an hour, with considerable loads, was attained, and, in 1825, the use of locomotive power was authorized by Parliament on the Stockton and Darlington Railway, constructed under Stephenson's direction.

When the Liverpool and Manchester Railway Company had obtained their Act, in the year 1826, it was not decided whether the means of transport was to be by fixed or locomotive engines, but in 1829, when the works were nearly completed, the latter mode was determined on, after a very full investigation, as being much less expensive than working by fixed engines.

Stephenson's success in producing, in the latter year, an engine capable of travelling at an average rate of 14 miles an hour, is too well-known to require any detail of the circumstances, besides being unsuited to the object of our narrative;

but the profession, having had an origin common to both countries, and its members not being confined to practice exclusively in either, I considered it of some interest to give a brief notice of the small beginnings which have led to such world-wide results; producing in no country more decided ameliorating effects than in our own, and teaching us an encouraging lesson by showing, that, while it was not permitted to the inventors to foresee the results of their labours, yet they have produced, in scarcely more than a quarter of a century, an industrial revolution throughout the civilised world, and that which was first intended solely for the transport of heavy burthens, has derived its chief importance and remunerativeness from passenger traffic.

The great success achieved in England, in 1829, was not long in producing an effect with us, for, in the year 1831, the Dublin and Kingstown Railway Company was incorporated, and this effort at adopting the new mode of locomotion was certainly more indebted to the special omnibus character of the line for its having answered, in a remunerative point of view, the expectations of its projectors, than to the economy of its construction.

The whole length extending 6 miles, for the most part along the sea-beach, from which it is protected by a pavement and sea-wall, of hammered stone, presented no difficulty to be surmounted; the cost, however, amounting to £70,000 per mile, is somewhat startling to our present ideas, but when it is recollected that, at the period of its formation, such works were more of an experimental character than following any settled mode of operation, and that the price paid as land compensation was extravagant, we shall cease to be less surprised at the cost than at the fact that its passenger traffic is highly remunerative, and that the Dublin and Wexford Company, who have extended the coast line to Wicklow, and who rent the Kingstown Railway, are realizing a profit, after

handing over to the proprietors of that line 8 per cent. on the capital expended. So little was such a state of things anticipated at the outset, that it was the goods traffic which was looked to for profit, and for that purpose it was proposed that there should be a custom-house at Kingstown, where ships were to unload their cargoes, to be thence carried by railway to Dublin.

In fact, greater ignorance than might be supposed prevailed with respect to everything connected with the new system. It appears from evidence taken before Parliament on the Southampton and the Great Western Railways, in 1835, that the removal of excavation was calculated to be done at 4d., 4½d., and 5d. per cubic yard, at an average lead of a mile, and that an additional lead of two miles would only make a difference of 1d. per yard. The inclination through the box tunnel, 1 in 107, was proposed to be worked by a stationary engine, on account of the supposed noxious effects of the fumes from a locomotive engine, and the learned Dr. Dionysius Lardner, having been asked if such a tunnel, in the middle of a line, could be considered as practicable, replied, that, from the general want of experience on the subject, he hesitated in answering the question, but he would be very apprehensive of it, and, at all events, that the ordinary mode of ventilation by shafts would not answer.

A number of rival schemes having been set on foot after the completion of the Kingstown Railway, the Government, acting on the advice of Mr. Drummond, R.E., who had been previously engaged on the Trigonometrical Survey, appointed a Commission, in 1837, consisting of that gentleman, Colonel Burgoyne, Peter Barlow, and Richard Griffith, Esqrs., in order to lay down a system of Railways in Ireland, with a view to the gaining of the greatest advantage by the smallest outlay, so as to guide the legislature in the projects that might be laid before it, and to prevent the waste of capital by an

accumulation of operations towards the same object, which was producing so injurious an effect in England. Under this Commission, surveys were made, and lines laid down towards the south-west, by Mr. Charles Vignolles, connecting Dublin with Cork, Limerick, Waterford, and Kilkenny, the latter by a branch from the trunk, at Maryborough, and another branch from Holycross, round the Keeper Mountains, through the Golden Vale, to Limerick. To Mr. John Macneill was entrusted the Survey towards the north, connecting Dublin with Armagh, from which to Belfast a railway was then under execution, and from Dublin to Enniskillen, the line as far as Navan being common to both.

The atlas accompanying the Second Report is an admirable example of the manner in which the preliminaries of a general railway system, adapted to the wants of a whole country, should be laid down. That portion of the labours of the Commission, prepared under the direction of Lieutenant Harness, R.E., consists of 6 maps:—1. Showing the lines laid down under the direction of the Commissioners, and those proposed by private parties. 2. The comparative density of the population. 3. The relative traffic in different directions. 4. The relative number of passengers in different directions. 5. The geological map of Ireland. 6. A map of England and Ireland relative to the communication between London and Dublin. The outline of the geological structure of the country was written by Mr. Griffith, and a great variety of information was obtained which must always render this Report a valuable record, although it was not followed by the desired results, as the death of Mr. Drummond, and the passing of the Government into the hands of a minister who held that enterprise should regulate itself, caused a well-devised system to give way to a principle which pre-supposes that speculators should know the best means of attaining what they want, in matters with which they are unacquainted,

and that professional advisers are the most skilful and disinterested guides that can be found; whereas, all experience in cases of rival schemes goes to prove the contrary. We have, however, in this country, principally owing to our want of wealth, escaped much of the evil of competing lines; but the defeat, by small local interests, of the great system laid down for the general benefit has not been without its manifest ill consequence, and, with the exception of a large portion of the main trunk of the Great Southern and Western Railway, lines—for the most part, rejected by the Commissioners, and for some of which Acts of Parliament had been previously obtained—have been carried out in situations not calculated to give the best returns; whilst in others, the effect of the competition of more judiciously selected lines, subsequently executed, must produce injurious effects. The connected lines, under different managements, betweeen Dublin and the North, furnish a strong example of the necessity of a systematized plan of communication being laid down in the first instance under proper control, for the conflict of separate interests is there found to be, not only injurious to the companies themselves, but a source of inconvenience to the public, nor does there appear to be any reasonable prospect of such a reconcilement of objects that ought to be common to all of them, as would lead to an amalgamation to solve the difficulty.

The Dublin and Drogheda Railway Company obtained their Act of Incorporation in 1836, but the line not having been approved of by the Railway Commissioners, owing to its running along the coast, difficulties impeded its commencement until the year 1840, when the first general impetus was given to railways in Ireland. It was opened to Drogheda in 1844, and has been since extended to Navan and Kells, with a branch to Howth, making a total length of 63½ miles, constructed at an average cost of about £15,000 per mile. The cost of the main line being about £22,000 per mile. It is to

be regretted that the embankment by which this railway is carried across the Clontarf strand was not made the means of reclaiming a considerable extent of mud-land, by excluding the tide, and altering the course of the Tolka river, in a line parallel with the high-road, and discharging it sea-ward of the pier at Crab lake.

The generally champagne character of Ireland has not presented much opportunity for engineering works of such importance or difficulty as to entitle them to special notice, there are, however, a few exceptions, amongst which the connecting link between the Drogheda Railway and the Belfast Junction may be here noticed, although out of place as to time, having been erected long subsequently by the latter Company. The Boyne viaduct, constructed under Sir John Macneill, as Engineer-in-Chief, with the assistance of Mr. Barton, crosses the river, from which it takes its name, a short distance below the town of Drogheda. It has three openings spanned by lattice girders. The centre opening is 264 feet in the clear between the piers, and the side openings have each a width of 138 feet; giving a length of 540 feet for the lattice beam, the depth of which is 22 feet 6 inches, and being connected over the supports, forms one continuous beam throughout. Fifteen semicircular cut-stone arches, 61 feet span each, of which 12 are at the south side and 3 at the north, complete the sustainment of the roadway, the whole length of the viaduct being one-third of a mile. The height from high water to the underside of the lattice beam is 90 feet, so required, no doubt, for navigation purposes, and giving a very imposing and hardy effect to the whole, which reflects the utmost credit on the skill brought to bear on its design and construction.

The Great Southern and Western Railway, extending between Dublin and Cork, was the first line of any considerable extent executed, and deserves to be ranked amongst

the most important and successful undertakings of this nature in the United Kingdom. It was commenced in the year 1844, under Mr. (now Sir John) Macneill, and, having presented no work of difficulty but the Rathmore tunnel (within a short distance of Cork), was opened to that point in October, 1849.

The permanent way of the Irish or 5 feet 3 inch gauge, is laid with a bridge-rail, weighing 90 lbs. to the yard, supported on transverse sleepers, which were introduced by Sir John Macneill, the same description of rail having been first used by Brunel on longitudinal timbers. A heavy rail of this description, well sustained, and easily adjusted, affords facilities for adopting the prienciple of taxing powerful engines instead of the public, and by thus extending cheap accommodation to all classes, giving encouragement to the sources of remuneration. The main line is 166 miles in length, and, with branches to Carlow, Athlone, Parsonstown, Fermoy, Killarney and Tralee, whose united length is 163 miles, gives a total of 329 miles, constructed at an average rate of about £16,400 per mile. The much cheaper construction of the branches diminishing the apparent cost of the main line, which amounted to about £20,000 per mile. The cost of the Rathmore tunnel, included in the rate per mile, was £100,000. It is 1,366 yards in length, 28 feet in breadth, and 24 feet in height, excavated through old red sand stone rock, of a not very solid kind, a small portion of it only in the centre being considered safe without lining; the gradient through it is 1 in 70.

The Midland Railway Company having been incorporated in the year 1845, became the purchasers of the Royal Canal for the purpose of constructing their line in connexion with it, deviations had to be made in some instances on account of the impracticability of the curves, and there is, throughout its course, in connexion with the Canal, as far as Mullingar, such

continuous winding as to prevent any very high speed being attained; the saving made, however, in the purchase of land, and in neutralising the opposition of the Canal, were considered to counterbalance the drawback in speed; the repetition of the old error, as to the proximity of the two great railways, like that of the canals, not having been taken into account—a mistake properly referable to the Directory rather than to Mr. G. W. Hemans, the Engineer, under whose skilful management the works were completed.

The line from Dublin by Mullingar to Athlone was executed at a cost of about £14,000 per mile. From Athlone to Galway, a distance of 48 miles, the railway was constructed for a sum of £500,000, lent by the Government, at 3 per cent., to the Midland Company, the interest being guaranteed by the County of Galway. The traffic on this extension was for some years unable to pay the working expenses and interest, but latterly there has been, with some exceptions, a small annual surplus. The Viaduct across the Shannon, supported on iron cylinders, and the bridge at lough Athalia, near Galway, are the only works out of the ordinary facile character. There are, with the Cavan and Longford branches, 192 miles in operation; and, although a large portion runs through districts not remarkable for their productiveness, yet the traffic enables the proprietors to receive a dividend of 5 per cent., free of income tax.

The railway connexion of Galway with Belfast, by the link about being completed from Clones to Cavan, between the west and north of Ireland, promises important results if the transatlantic communication be successfully carried out. It is quite true that a packet station does not necessarily of itself enrich a port, but if the raw cotton of America were brought to the water-power of Galway, and returned in fabrics of a coarse description as back loading, it would create a remunerative trade, having for its encouragement the saving of 300

miles of sea carriage upon the raw material imported, and as much on the cloth exported—the saving of the Liverpool port dues, and of the railway freight into the Lancashire cotton districts—the saving of time and interest of capital between the period of the raw material leaving America and returning as cloth, and finally, the saving of water-power as against steam, which, allowing for capital sunk in machinery propelled by water in the one locality, and by steam in the other, may be taken at £5 per diem for every 100 horse-power. This trade would lead in time to higher branches of cotton manufacture, and an European market would thus be, for the first time, established in Ireland, with the important adjunct of a highly-subsidised mail packet service, forming so favourable a combination of circumstances as, judging from the results of much less promising beginnings, would justify sanguine expectations of great results. The passage from Galway to Newfoundland having been made, during the last year, in 5 days, by one of the vessels of the Transatlantic Mail Company, has been a great step towards settling the question submitted to the Railway Commission of 1838, as to the port on the west or south coast of Ireland from whence navigation to America might best be carried on; but that success cannot be taken as conclusive against other rival ports, as, for instance, Bearhaven, Valentia, Tarbert, or Cork, which latter offers advantages as a port of call.

A notable result of the construction of railways has been the development of the contract system, which, while on the one hand it has had a beneficial effect in aiding engineers, by dividing the labour with practical and responsible subordinates, has on the other hand, by means of liberal banking accommodation, afforded to the holders of large contracts, tended to create a monopoly of the execution of works in the hands of a few, who having eventually become influential capitalists, were in a position to make combinations unfavourable to

economical construction, more particularly in cases where part payment was agreed to be received in shares by the contractor; but with an engineer of skill and integrity, and sufficient funds at the command of the company, the competitive contract system, based on detailed quantities and prices, has been found a safe course to pursue.

This subject could hardly be referred to without noticing the name of Mr. William Dargan, who was the contractor for the greater portion of our principal railways; and having, by that means, amassed a large fortune, he undertook, at his own risk and cost, the Great Industrial Exhibition of 1853, which was honoured by the presence of the Queen as a mark of Her Majesty's high appreciation of successful enterprise and public spirit. A baronetcy, offered as a further proof of royal favor, was declined. The receipts of the Exhibition are said to have fallen short, by £20,000 of the expenditure, which was about £80,000.

Although railways, as commercial speculations, might have been rendered far more profitable than they are, yet their construction and management in Ireland, when we look to what has occurred with our neighbours, must be considered to be attended with considerable success. The average cost of construction in England has been £38,779 per mile; in Scotland, £27,532; and in Ireland, £15,061 per mile; and taking the lines constructed since 1848 only, the average cost per mile in England, was £12,600; in Scotland, £8,700; and in Ireland, £6,600 per mile. The difference in the price of land and labour in the two countries will undoubtedly make up some of the difference of cost, but will not account for the whole of it; and that there is a good deal due to management is proved by the fact, that the proportion which the working expenses have borne to the receipts has been, for the year 1858, in England, 50 per cent.; in Scotland, 44 per cent.; and in Ireland, 40 per cent.

We have now 1,188 miles of railway, in Ireland, in actual operation, in a period of scarcely more than 20 years, constructed at a gross cost of seventeen millions and a-half, establishing communication between almost all the important towns of the country and Dublin, which is itself about to be brought, by a new postal arrangement, within eleven hours of London—an achievement considered impracticable at the time of the Irish Railway Commission of 1838, in the Second Report of which it was anticipated, as a great result, that the two Capitals would be brought within 20 hours of each other!

The application of atmospheric pressure to locomotion was first proposed, in 1834, by Vallance, of Brighton, for the transmission of letters. The contrivance of which a model was exhibited, consisted of a tunnel to receive a carriage at one end, and the air being exhausted by a steam engine at the other, rapid propulsion was obtained. Ten years later, Pinkus brought forward a plan for making the carriages travel outside the tube; and in 1839, Clegg and Samuda patenteed their improved method, and exhibited it in 1840, working on Wormholt scrubs, on a length of about a mile. The success of that experiment induced the proprietors of the Kingstown railway to adopt the system on the extension of their line to Dalkey, a distance of 3,050 yards. The line was single, of the ordinary kind, and in the centre, between the rails a tube of 15 inches in diameter was laid, having a longitudinal opening at the top, closed by an elastic valve, and an entrance and exit valve at either extremity; a piston, fitted to the leading carriage of the train, was inserted into the tube at one end of it, the other extremity being connected with a condensing expansive steam-engine of 100 horse-power, by which the air was exhausted, and the piston being forced forward by the pressure of the atmosphere, the train was drawn with a velocity proportioned to the degree of vacuum produced. As

the piston advanced the valve in the slit of the tube was opened, and closed again after the piston had passed. A composition, principally consisting of grease, placed in the groove into which the valve, lined with leather, fell, rendered the tube impervious to air. The gradients were very steep, being in some places 1 in 50, enabling the trains to return from Dalkey by gravity alone. The system was tried on a more extensive scale on the Croydon, South Devon, and Orleans Railways, where a speed of 60 miles an hour was experimentally attained; and in the regular course of traffic on the Dalkey line, a train of 10 carriages, weighing 50 tons was propelled at the rate of 35 miles per hour, the barometer indicating a vacuum of from 25 to 28 inches. From the date of the opening in 1843 to 1856, when a further extension was made to Wicklow, the pneumatic action appeared to work, as far as the public were aware, in a satisfactory manner, and without interruption; but in the latter year the gradients of the Dalkey line were altered to suit locomotive engines, and the atmospheric system was given up, being found less sure and effective as a mode of propulsion.

In looking back to the period of the canals, already described, and comparing it with that of the introduction of railways, we see that, although more than half a century had intervened, during which the United Kingdom had made great advancement, as well in general knowledge as in material wealth, yet there was no more exemption from errors of a grave description at on period than at the other. The peculiar advantages attendant on rapid communication being the principal element of success of the new system, in a commercial point of view, while it afforded great opportunities for developing professional skill, eventually equal to the occasion, although too often with results obtained without sufficient regard to the profitable employment of the capital invested.

The construction of railways, although of a routine charac-

ter generally, has, undoubtedly, by their magnitude and importance, raised the profession to a position it had not previously occupied in public estimation; and, looking to the general outline that has been traced, it is not without interest to observe the steps by which advances were made in professional attainments, during a period of not more than a century since the founders of the school of engineering arose in these countries. We see that, from want of a well-established combination of scientific and practical training, knowledge progressed not steadily and uniformly as in the exact sciences, but according as opportunities were afforded for practice, leading finally, by increased demand, to a division of labour, by which our profession, properly embracing all that concerns mechanical construction, having left architecture to its natural alliance with the fine arts, has been divided into three distinct brances, the first comprising structures in masonry, timber, iron, and earth work; the second, mechanical engineering; and the third, mining engineering. These divisions are now tolerably well recognised, but there are individuals who exercise all with success, as well as those again who devote themselves to a special sub-division, thus elaborating each part, and leading farther from the field of empiricism into the sphere of systematised knowledge, for which ample opportunities have been afforded, without having produced a corresponding advance in high scientific attainments; for, in this latter respect, notwithstanding the great practical superiority of the English school, there can be little doubt that it has not kept pace with those either of Germany or France, as their publications abundantly testify; the English Institution, however, has made great advances in the exposition of the principles of applied science since its establishment in 1818, and many of its members may contemplate with just pride the results of their labours in the monuments of commercial greatness with which their country abounds.

The foundation of this Institution in 1835, under the Presidency of Sir John Fox Burgoyne, Chairman of the Board of Public Works, was, in itself, a proof of the improved position assumed by the profession in Ireland, in calling for the means of recording and discussing practical results, as well as forming a rallying point, without which the body could have no joint action or cohesion. Be it our duty, by a zealous fellowship, to elevate and perpetuate its career, leaving professional rewards to follow in the wake of knowledge thoroughly acquired, and exercised with a judgment and spirit which scientific training can alone impart.

I am now obliged to bring to a premature close this imperfect and, somewhat disjointed narrative, with the intention, however, of supplying the deficiencies at a future period, when more leisure shall permit. I became aware as I proceeded, that the limits of an address, and the time afforded for the reading of it, were ill-suited to the number of subjects, and the variety of details to be treated of, presenting many difficulties to the explorer in an untrodden field, I must, therefore, throw myself on the indulgence of the Institution for the many omissions which have unavoidably occurred, there being no possibility of embracing the whole subject in the form at first proposed, except by a compilation of mere annals—a difficulty in itself where no regular record existed—and in avoiding that uninteresting task, I have been obliged to postpone many subjects essential to the history of the profession, of which I intended this sketch to be the basis, in order to provide for a want always becoming, by lapse of time, more difficult to be supplied.

[May 10th, 1859.]

M. B. MULLINS, Esq., President, in the Chair.

DESCRIPTION *of a* JOINT CHAIR *for* BRIDGE RAILS, *designed by* MARCUS HARTY, Esq., Engineer to the Dublin and Drogheda Railway.—By WILLIAM ANDERSON, Esq., Member.

MR. ANDERSON exhibited a joint chair (Plate II., Figs. 1 and 2), for bridge rails, designed by Marcus Harty, Esq., Engineer to the Dublin and Drogheda Railway. He explained that when rails are jointed on a single cross sleeper, without any rigid connexion, such as fish plates, which are inapplicable to bridge rails, the advancing train presses down one side of the sleeper first and, on leaving the joint, depresses the other, causing a rolling motion, the effect of which is very injurious to the fastenings and renders a rigid joint impossible. To obviate this, the chair before the meeting was designed. The joint of the rails rests on the centre of the chair, the ends of which are carried by the ordinary sleepers; the bottom flange of the chair is thicker in the middle than at the ends, so that the rails only bear in the centre, and the weight of the passing train is nearly evenly divided between the two sleepers. The rails are secured to the chair by means of four $\frac{3}{4}$-inch bolts, with lock-nuts; the holes in the rails are elongated, to allow for variations in length, due to differences of temperature; and to guard the bolts from side strains, two thin plates are placed under the nuts. The chair and rail are secured to the sleepers by a single spike in each. The rib of the chair is made slightly narrower at the ends for the convenience of laying curves. When the chair, represented in Fig. 1, is used,

the joint sleeper is dispensed with, and the pitch of sleepers remains unbroken. A shorter chair, adapted to old roads, of which the centre section is given at Fig. 2, was tested at 2 feet span with the following result:—

Weight on Centre	Deflection	Permanent Set
3 Tons, . . .	0·02″	Not perceptible.
6 ,, . . .	0·06″	d° d°
8 ,, . .	0·12″	0·03″
10 ,, . . .	0·28″	0·17″
11 ,, . . .	0·52″	0·39″
12 ,, . . .	Broke through bolt holes.	

Harty's chair has been extensively used on the branches of the Great Southern and Western, on the Dublin, Wicklow, and Wexford, and on the Dublin and Drogheda Railways, with most satisfactory results.

[13th December, 1859.]

M. B. MULLINS, Esq., President, in the Chair.

DESCRIPTION *of a* SIX-TON CRANE, *with* CURVED, DIAGONALLY BRACED JIB, *at the* PIGEON-HOUSE FORT, DUBLIN.—By WILLIAM ANDERSON, Esq., Member.

CURVED crane jibs, the author believes, were first introduced by Mr. Wm. Fairbairn, who constructed them with plate sides, like curved tubular beams. This advantage of form, for lifting bulky articles, was obtained at a sacrifice of facility for cleaning, painting, and repairs, or for replacing and adjusting the chain

and guide rollers, while the close sides offered a large surface to the wind, rendering the crane more difficult to handle in stormy weather.

The general features of the crane are shown on the diagram (Plate I). It consists of a wrought-iron curved jib, with the centre of the chain pulley 18 feet above the ground, and describing a circle of 18 feet radius. At the level of the ground the jib is supported by live rollers, running in a cast iron curb; while the foot of the crane rests on a footstep, sunk 10 feet in a well of masonry.

The jib at the footstep is 1 foot 6 inches square, at the level of the ground it is 3 feet deep, and 2 feet 6 inches wide, diminishing gradually to the chain pulley, where it is 1 foot 9 inches deep, and 13 inches wide. The flanges are formed of plates and ⊥ iron, the latter being connected by the diagonally braced sides, formed of angle iron struts and flat iron ties.

The general arrangement of the bracing and geering having been decided, a skeleton diagram was constructed representing the lines of strain, the jib assuming the appearance of being built up of triangles, the outlines being polygonal, instead of circular, for facility of calculation. By means of parallelograms of forces the effect of the load was traced downwards, from the point of the jib to the roller path, through the flange, and bracing, and upwards, from the footstep to the roller paths and, as the author anticipated, the one investigation checked the other, that is to say, the amount of force tending to tear or crush the flanges at the roller path, where the greatest strain is, was found to be identical, by working downwards from the load, or upwards from the pressure on the footstep.

By the method of moments round any given point in the flanges of the jib, it is possible to arrive at the strain in any particular portion, without being obliged to travel down from its point, and by this means a ready check can be applied to the work.

Without detaining the meeting by tracing the forces throughout the crane, it may briefly be stated, that the strain in the flanges continues to increase from the end of jib to the roller paths, and to diminish again from the footstep, while the strain, in this particular case, in the bracing diminishes gradually as the curve of jib approaches the perpendicular, when it disappears altogether. The strain in the bracing, below the roller path, also varies similarly throughout, the pressure, laterally, against the roller path and footstep being equal and opposite, and the angle of the bracing the same.

Although, for a vertical force at the extremity of the jib, no bracing was required in the vertical and parallel portion of it, yet as cranes have frequently to drag loads towards them, from a distance, thereby altering the magnitude and direction of strains, it was deemed prudent to carry the braces throughout, while the plate sides, 2 feet above the ground, were introduced to protect the inside of crane from dirt and rubbish, and to aid in securing the roller path and geering. The unit strain was fixed at 3 tons to the square inch, both for tension and compression, making the probable breaking load of crane 30 tons.

The footstep of the crane is inverted to prevent the lodgement of grit; but it is doubtful if this is an advantage, for the oil runs away too freely, and the author would not recommend its adoption in a crane likely to be very much used. The pin is of cast iron, solid, with a base plate 2 feet 6 inches square, sunk into, and bolted to the bottom of well; it is 5 inches in diameter, to resist a lateral strain of 12·3 tons, besides the weight of the jib, or about 0·6 tons per square inch of area. The lateral surface, in firictional contact, is 23½ square inches, bearing, therefore, about ½ ton to the inch. The step is of brass, suspended from the bottom shoe of the jib by means of 4 bolts 1⅛ diameter, by which arrangement the crane can be raised as the brass wears, or, the bolts being withdrawn, the brass

can be removed for cleaning or repairs. Oil is supplied by a pipe carried to the surface.

At the level of the ground is a circular curb of cast-iron, bolted to and built in the masonry. On the inside is a turned roller path 5 feet 8 inches diameter, 6 inches broad, against which roll 8 cast-iron rollers, 6 inches diameter, carried in a "live ring," travelling on 4 bevil rollers disposed under it. A strong casting, having a turned external roller path, is bolted and keyed to the body of the jib, which turns round upon the 8 rollers above named. An annular toothed wheel is secured to the curb, and acts, through ordinary gear, as a fulcrum for turning the jib round.

The apparatus connected with the hoisting gear is all bolted to the jib, by means of pedestals and brackets, so that in case of fracture or wear from use, it is very easy to replace any part without making expensive patterns. The chain barrel is 18 inches diameter, 1 foot 10 inches long, to coil 50 feet of $\frac{5}{8}$-inch chain in one lap, this is very important, as the "riding" and unequal lapping of chain, coil upon coil, on small barrels is a fruitful source of accidents. The chain may be rove through a snatch block, and its hook carried up to and hooked into an eye bolt, under the point of jib provided for that purpose, or, for light and rapid lifts, it may be used single, without the block. In this way the powers are 13, 26, $82\frac{1}{2}$, 165 to 1, and, adding 25 per cent. for resistance of friction, 4 men, exercising a force of 25lbs. each on the handles, can lift 6 tons, 3 tons, 1 ton, $\frac{1}{2}$ ton.

The chain is carried over a guide pulley, free to travel across on a bar, inside the jib, and thence to the sheave in the end of jib, which has cast iron cheeks rivetted on to receive the journals.

On trial the crane was found to work very well; the deflection of jib, with 6 tons, was $1\frac{1}{2}$ inch, without any perceptible permanent set.

There are two defects in this crane: 1st.—The well in which the jib works should have been made water-tight, either by very substantial masonry or cast iron lining; as it is, it fills with sea-water at every tide, to the detriment of the machinery and plates. 2nd.—The turning gear is too quick, it requires only 14 revolutions of the handle to turn the crane round, and although it works very easily the author thinks the speed at which a heavy load may be made to swing round might lead to accident in carless hands, and he would very much prefer the speed reduced fully one half.

INAUGURAL ADDRESS

DELIVERED AT THE

INSTITUTION OF CIVIL ENGINEERS OF IRELAND,

ON THE

EVENING OF THE 19TH OF FEBRUARY, 1861,

ON THE OCCASION OF ITS FIRST MEETING

IN THE

NEW LECTURE HALL OF TRINITY COLLEGE.

BY THE PRESIDENT,

SIR RICHARD GRIFFITH, BART., LL.D, F.G.S.,

ETC., ETC.

GENTLEMEN,

At our last meeting, I mentioned that although, at this advanced period of my life, I had determined not again to undertake any new labours or responsibilities, still, under the peculiar circumstances in which our Institution is placed, and at the request of our Council, I have consented again to assume the reins of office, and become your President, but, on the express undertaking by my friends of the Council, that they would endeavour to lighten my labour as much as possible, and thus render my unavoidable absence from this chair, when engaged in special public business, less inconvenient and injurious to this Institution, than it might otherwise be.

I have now, gentlemen, the pleasure to congratulate you on the arrangement which has been authorized by the Board of Trinity College, according to which we are at present

met within the walls of the ancient University of Dublin; by which kind act of the College Authorities, we are, I may almost say, affiliated to that noble establishment, and our relationship with it will become gradually more intimate and more beneficial to ourselves, such being, in fact, a legitimate result of the position we hold as a scientific and practical Institution, and in this view it appears to me to be desirable to offer a few remarks relative to the part which Trinity College has taken in the advancement of our profession in this country, by engrafting *on* academical instruction the study of the several sciences necessary for the education of a Civil Engineer. But I may go farther back, by observing that almost simultaneously with the revival, as I may almost term it, of mathematical science in the University of Cambridge, through the exertions of Dr. Peacocke, the distinguished Dean of Ely, as well as by those of Dr. Whewell and Sir John Herschell, a similar movement took place in our own University, mainly through the instrumentality of my old and valued friend, the late Doctor Bartholomew Lloyd, by whose personal influence, in addition to that of his able work on Mechanical Philosophy, an impulse was given not only to the extended cultivation of mathematical science in this University, but, as might be expected, to the more active cultivation of science in general; and I may mention, that the introduction of the writings of such men as *Lacroix*, *Poisson*, &c., and of the improved methods of modern mathematics into the courses of the University, was principally owing to the exertions of the late Dr. Lloyd.

Although the *chairs* of Botany and Chemistry existed in the University since the year 1785, in connexion with that of Anatomy, still they could not be regarded as of general advantage, being limited, in fact, to the students in medicine; but—in advance of the lectures delivered by the late Dr. Percival, in the year 1805, which it was my privilege to

attend,— upon the appointment of the late Dr. Whitley Stokes, in the year 1816, to the Lectureship of Natural History, which, in reality, combined zoology, mineralogy, and geology, an approach was attempted by which the system at present in existence may be said to have been foreshadowed.

And here, gentlemen, I may be permitted to mention the establishment of the Geological Society of Dublin, which, with the assistance of his son, Dr. Humphrey Lloyd, was founded by my friend, Dr. Bartholomew Lloyd, who was, at that time, Provost of Trinity College, and the first meeting of that society (at which I was present) was held in the library of the Provost's house, in the year 1831, Dr. Bartholomew Lloyd being the first President.

I am sure I shall be excused for making peculiar reference to that institution, as it has been one with which I have been myself identified since its formation, and it has been mainly instrumental in keeping alive a spirit of geological inquiry in this country, which I expect will increase rather than relax, from its direct connexion with the University, as well as from the zealous presidency of my friend, the Rev. Samuel Haughton, who I am happy to recognize as a fellow-member of our Institute of Civil Engineers.

It is also satisfactory to know, that it has been arranged, that both the Geological Society of Dublin and the Institute of Civil Engineers of Ireland should, in future, meet, possibly at the same time, in the Lecture-Halls of this University, and, having many members in common, it is to be hoped that the facility of intercourse thus created, will cause a mutual interest and familiarity which must tend to the advancement and usefulness of both Institutions.

While referring to this subject I may be pardoned for, perhaps, an undue partiality to a favourite science, if I endeavour to direct the attention of the members of this Institution, in a special manner, to the advantages which our

profession must derive from a practical acquaintance with geology.

Omitting much that might be said relating to the importance of mineral surveys, mining, estimation of the value of lands, (the soils of which so frequently result from the disintegration of the subjacent rock,) rock cuttings, and especially tunnelling, and other works of a similar character, which may be expected frequently to occur either directly, or in connexion with the more general undertakings of the Civil Engineer, I may refer to the advantage of being enabled, through an acquaintance with geology, on entering a strange district, to determine, in addition to the levels, the best general course for a line of road, or railway, &c., having regard to the rock cuttings, as well as to the procuring of suitable materials for building at a comparatively cheap rate, and by this means becoming at once at home in the district, and capable of taking advantage of all the facilities which it may afford, many of which might otherwise have escaped notice.

I will not be understood as recommending a mere conversational acquaintance with the respective theories of this or that school of speculative geology, which falls far short of the practical knowledge which can only be acquired by careful observations in the field. On the contrary, speaking from my own experience, I should rather expect to confer benefit on both the profession and the science, by the unbiassed exercise of actual observation, having, at the same time, as much regard to systematic arrangements as would enable the observer to communicate new or unusual facts, with the conclusions resulting from their consideration; and, consequently, every suppression of ascertained facts is injurious to the advancement of knowledge, and its extension to practical results, and in consequence we deem it an unworthy and illiberal view to limit the profession to its more apparently direct or routine

operations, without having regard to those aids, which, though remote in appearance, form an important feature in all great undertakings, and hence I would leave such views to those, who, being unacquainted with geological science, undervalue its application.

It is unnecessary, further, to press this subject on the consideration of the Institution, so many instances of its advantage will arise spontaneously in the minds of many, such as the indispensable knowledge of cleavage in the selection of workable slate quarries, of the composition and texture of superior materials for flagging, of jointing, and lithological character, as bearing on the expense of raising blocks of stone, of being able to ascertain the probable continuance of certain strata in their direction or strike, or from their mineral composition, with numerous other matters to which it would be superfluous to refer, as no doubt I have been anticipated by many gentlemen present, and I should not have so far trespassed on your patience, had I not thought it desirable that our junior members should be made aware, that Civil Engineering is not limited to the bare exercise of formal, mathematical, and mechanical appliances, and that those, who aspire to the higher walks of the profession, should avail themselves of every opportunity of making mineralogical and geological observations in the field.

But to return to the progress made in the study of science, as applicable to our profession, in the University, I may observe that, upon the death of the late Dr. Whitley Stokes, which occurred in the year 1845, a subdivision was made of the sciences previously attached to his chair, by the subsequent appointment of my friend, Professor Phillips, (now of the University of Oxford,) to the chair of Geology, the subject of mineralogy being transferred to the professor of chemistry; while, since the year 1858, on the death of Dr. Harrison, the late eminent professor of anatomy, who lectured

also on zoology, a separate lectureship in that science has been established.

About the year 1840, when the establishment and gradual extension of the railway system in England, had attracted universal attention throughout Europe and America, it became evident that Civil Engineering should be considered as one of the learned professions. With this view, schools were established in England by the joint exertions of private individuals, as a remunerative commercial speculation, and subsequently schools for a similar purpose were attached to the New University of Durham, and also to King's College, London; and in the year 1841, when the importance of founding a scientific and practical school of Civil Engineers in this country became evident, it was at once established in our University, with the view, as I have already observed, of combining the theoretical and practical instruction requisite for the profession of a Civil Engineer, and at the same time of imparting to its members, along with the other advantages of academic education, a more accurate and extensive knowledge of geology, mineralogy, and chemistry, as applied to the arts of construction, rendered necessary by the formation of this school; hence it became necessary to call in the assistance of special professorships, in addition to that of Civil Engineering, which latter was created in order to carry out the scheme, and Sir John MacNeill was selected as professor, who, having resigned, was succeeded by the present able professor, my friend Dr. Downing, he having previously filled the office of Lecturer in Engineering, which had been held by Lieutenant Rennie in the first instance.

The creation of these offices had further become necessary, owing to the fact that the subjects I have mentioned, had begun not only to assume a greater degree of prominence, but also, as it was determined by the College Authorities, in the year 1850, that, with the exception of engineering itself, they

should form a portion of the University curriculum, for such students as might prefer to pass in such branches of study, omitting others not necessarily required by the pupils of the engineering school, nearly all of whom, besides taking their license of qualification, or diploma, also matriculate in arts, and become graduates of the University.

Before proceeding with this subject, I must express the gratification I feel, in being able to refer to the fact, that, as we are indebted to the late Provost Lloyd, for the impulse given to mathematical science in this country, and for the formation of the Geological Society of Dublin, so, (as I well remember,) have we to attribute the foundation and origination of the University School of Civil Engineering, to the zeal and activity of his son, my friend the present Dr. Humphrey Lloyd, who, as the Agent of the College Authorities, in his capacity of Erasmus Smith's Professor of Natural and Experimental Philosophy, issued all the preliminary documents and circulars, and having arranged the programme necessary for its institution and organization, finally opened it, for the admission of students, by an inaugural address; and I think we cannot but feel grateful to him, in addition, for the kindness he has always shown, and which is still continued to the Geological Society, by devoting his rooms to its service, similarly, to the generosity to which I find reference in the Report of our Council, with respect to the accommodation which our Institution now enjoys in the rooms of my friend the Rev. Professor Haughton.

As I before stated, the University School of Engineering was founded in the year 1841, when it was considered desirable, not merely to regulate the profession, and stamp it with an academic character, but also, as far as possible, to promote the combination of professional, with ordinary collegiate education, so as to fit the students for the higher walks of the profession of Civil Engineer. With a view to effect this

object, it was determined by the Board of Trinity College, that all the students in engineering should be also members of the University during their course, and the consequence has been, that few students have received the License or Diploma of a Civil Engineer, who have not also taken a degree in arts; and further, during the last year, (1860,) it was determined by the Senate of the University, that in future, a license of qualification will be granted to successful candidates to practice the business of an Engineer, and that all Licentiates who have obtained the degree of Bachelor in Arts, and who have had three years' practice as Civil Engineers, are eligible for a new degree, entitled, "*Master of Engineering*," thus ensuring, not only a higher academic standing, but requiring a still further degree of attainment than was requisite for obtaining the Diploma of Engineering, as previously conferred.

Although I have entered more at length, than I had intended, into the system adopted in the School of Engineering, established by our University, I shall still advert briefly to the education and professional discipline which the College authorities have established, for effecting the object contemplated.

I find that the course of instruction necessary for Licentiates in Engineering, is extended over three years, during which time they are required to attend Lectures in Mathematics, Physics, Theoretical and Practical Mechanics, Hydraulics, Geology, and Chemistry as applied to the arts of construction, besides being trained to habits of accuracy and expedition, in the field, by the Professor of Engineering.

The Lectures of Erasmus Smith's Professor of Natural and Experimental Philosophy, who is likewise Registrar of the School, are also attended by the students in Engineering, and, I think, I need only mention the name of my friend, the Rev. Professor Galbraith, (who so worthily occupies the

chair once held by Doctor Humphrey Lloyd,) to satisfy us with respect to the nature of the instruction they receive.

I need hardly attempt to do justice to the Professor of Geology, as his varied scientific attainments do not require any comment, to render them more fully appreciated than they are at present; but I may refer to the valuable aid afforded to the students of the Engineering School, in Elementary Science, by the issue of the series of Publications, known as "Galbraith and Haughton's Manuals," which, with their personal exertions, as well as those of other distinguished Professors and Lecturers, are so well calculated to sustain the spirit originally introduced by the late Doctor Lloyd, the former Provost of Trinity College.

I must also notice the advantages derivable from the lectures of such instructors as the Rev. Professor Jellett, Dr. Hart, Dr. Salmon, Mr. Roberts, &c., &c., whose eminence in general Mathematical or Mechanical Science is so well known; while I may merely refer to the name of Dr. Apjohn, the Professor of Chemistry, in whom I am glad to recognize an old friend, as the public estimation in which he is already held, would not be increased by any eulogy from me.

In order to undertake the duties of Assistant Engineer, which, of course, every Licentiate must first become, the students, (for whose use, a large supply of instruments has been purchased), are instructed by the Professor in surveying and levelling, in addition to the varied practice of an Engineer, both in the field and office; and with a view to individualize the students as much as possible, in contradistinction to the principle of *collective teaching*, small parties are engaged in the field, alternately, under the guidance of the Professor, and afterwards without his assistance, the senior students being, at the same time, afforded the opportunity, when possible, of practice in connexion with actual public works, such as railways, &c., which, from time to time, may be in progress in

various parts of the country, while the models of both Civil and Mechanical Engineering contained in the museum attached to the School, afford the means of familiarizing the pupil with the objects, which, in his future career, must necessarily engage his attention.

The addition of the models possessed by our Institution, to those already in the Museum, will, no doubt, add much to the advantages, which such a collection is calculated to afford, and by an arrangement with the metropolitan directors of principal Railways, the students are afforded the means of practice in the workshops of the Mechanical Engineer departments belonging to those Railways.

The Chemical laboratory is also open to students in Engineering, enabling them, from the commencement to acquire a proficiency in chemical manipulation, so necessary in the practical and expeditious analysis, which will often facilitate the Engineer in many operations, which may arise in the course of his practice, on which account, the pupil is instructed by the Professor (Dr. Apjohn) in regard to the composition and effect of the various mortars and cements, as also with the character and analysis of rocks of every kind, which may be used as material for building, as well as with the nature of soils, waters, metallic ores, simple minerals, and any other objects, connected with engineering, which might be suitable for chemical enquiry.

The Professor of Natural Philosophy delivers three courses of Lectures on Galvanism, Magnetism, Optics, the Steam Engine, &c.; and the Professor of Geology, similarly, lectures upon Systematic and Physical Geology, besides the application of the science to many of the operations of the Engineer, together with the principles of mining, and the indications afforded in various geological researches by organic remains, all of which are exemplified, from time to time, by varied instruction communicated in the lecture room and in the field.

I should also refer to the attention paid to drawing in the School, for which purpose an experienced Engineering Drawing Master has been appointed to act under the direction of Professor Downing, and I cannot but feel gratified, that the gentleman at present occupying that position, namely, Mr. Campbell, (many of whose diagrams are now before us), has in a great measure, been prepared for such an office, by the experience he acquired while acting under my own direction, in connexion with the General Survey and Valuation of Ireland.

I have thus, gentlemen, dwelt at length on this subject, as it has appeared to me to be of paramount importance, especially, as the University School of Engineering is likely to become the nursery from which we may expect to recruit the ranks of our Institution, and in this view, I am happy to congratulate the young gentlemen of the school upon the connexion which in future they will have with our Institution, by the association of the Students of the Engineering School, (as determined by our Council,) to a participation in our meetings and discussions.

I may conclude this portion of my address, by referring to the general statistics of the school, since its foundation in the year 1841, which are as follow:—

I find that since the year 1843, there have been upwards of 130 Diplomas, or Licenses, issued to successful students in Engineering, and that since the year 1849, out of upwards of 100 qualified candidates, say, about one-third of the whole, have been awarded special certificates for distinguished answering at the final examination, in Mechanics, Experimental Physics, Chemistry, Mineralogy, Geology, and Mining, which, though no test of future professional success, affords the best means, at present in our power, of stimulating exertion and rewarding application. In looking over the lists of those, who, being qualified to practice by the University License, have entered upon various professional schemes of action, I find that some have risen to positions of eminence, amongst

whom, I may mention Mr. Barton, so well known for his connexion with the Northern Grand Junction Railway, and Mr. Bourne, the district Engineer at Monghyr, the principal station of the Calcutta and Delhi Railway; while others may be found engaged in various positions of home service, such as Resident and Assistant Engineers on railways, harbours, docks, and water works, besides county surveyorships and government appointments; and, according to the late lists, it appears, that upwards of 20 are engaged on the Indian railways and geological surveys, while some are engaged in Canada, Australia, the United States, and on the Continent, amounting in all, to, say, about 100 individuals professionally employed at the present time, in different parts of the world; from which facts it must be admitted, that the Engineers of the Dublin University School have succeeded beyond what could have been expected, from an establishment of comparatively recent formation.

I have now, gentlemen, to offer a brief review of our more immediate concerns, and I am happy in being able to congratulate you in regard to the general state of our finances, which I find to be, at the least, in an average condition; but, at the same time, I regret to observe that the contribution of original papers has not been such as might reasonably have been expected from an Institution of our pretensions, as, with the exception of one paper, the communications, during the last session, have been limited to the very detailed and valuable address of our late President, Mr. Bernard B. Mullins, the reading of which occupied three evenings, and which contains a minute history of the several important engineering works which have hitherto been executed in this country, and which will form an admirable foundation for a future historical account of civil engineering in Ireland. This valuable communication is at present in the press, and it will, no doubt, be studied with pleasure and profit by all our members.

It is, however, to be expected that the late apathetic silence of our members, *as a body*, will now terminate, and that fresh vigour will be infused by the stimulus arising from the present improvement of our position, by means of which the members, as formerly, will not have reason to complain of the length of time which may elapse between the reading and the publication of their communications, as, owing to the accommodation which has been afforded to our meetings, nearly the whole of our funds will be available for printing and illustration.

As an apology for the late paucity of original communications, to which I have alluded, it appears to me that our justification must be based on the consideration, that our Institution has been hitherto, (which, perhaps, may be regretted,) almost limited to the working members of the profession, who are, necessarily, independently of the pressure of their occupation, much dispersed, and that we have not, in consequence, a sufficiently numerous corps of regular contributors resident in Dublin to furnish the amount and variety of communications requisite to occupy the session; but it may probably stimulate our endeavours to suggest, that an original paper may afford matter for very profitable discussion without being either very long or abstrusely scientific, as the benefits derived from our Institution are, in a great measure, produced by the different views on each subject which are elicited by freedom of discussion, and for this purpose, subjects for short and suggestive papers will often arise in the course of even limited professional practice; thus ingenious applications of well-known principles, extemporized contrivances by which unforseen difficulties have been overcome, slight improvements on ordinary methods, or judicious and effective deviations from practices of mere routine, will form the materials (however briefly detailed) for subjects of communications of an instructive character; and in order to rival the vitality of other

societies, an increase of associate members is to be desired, by the introduction of gentlemen, who, though not perhaps strictly of our own profession, may yet afford valuable papers, and aid our discussions, which may lead to the enlargement of our views, when offered by persons whose pursuits are of a cognate character; nor is there an indispensable necessity that we should be solely confined to the description of projects which may have been successfully carried out by their respective authors; but, on the contrary, we may often advantageously occupy ourselves in considering little-known or novel inventions, or works belonging to British or foreign Engineers.

Though I have thought it advisable to allude to the deficiency of our late contributions, with a view to increased exertion in future, it should be borne in mind that such alternations of lassitude and vigour may be said to be a condition of all scientific societies, and we may be encouraged by the fact, that the London Institution of Civil Engineers, now so flourishing, has had its successive seasons of collapse and recovery, besides its periods of internal divisions and rival interests, the latter of which is probably a more fertile source of injury to an institution than any other, and I should hope that we shall endeavour to banish it from amongst us by mutual forbearance and avoidance of asperity in criticism, which last, (even when injudiciously resorted to,) should, after all, be considered as a sign of the healthiness and strength of our constitution, independently of the fact, that it is the undoubted right of every member of the Institution to exercise such criticism, provided his observations are advanced with good feeling, and solely for the purpose of arriving at just conclusions.

Upon the retirement of Sir Harry D. Jones, it was considered by many members of the Institution, that increased vitality would result from the appointment of a *civil* instead of

a *military* President, and, upon the failure of this expectation, a similar result was looked for by the removal of the Institution from the Custom House to Sackville street, whereby, being possessed of its own Museum and Club-room, as well as other conveniences, every cause of failure was supposed to have been removed, but, gentlemen, I need hardly refer to the fact, that no amount of judicious direction on the part of a President, nor of suitable appliances and conveniences, (however valuable in themselves), will form a substitute for what can only be supplied by our own personal and zealous exertions, a consideration which requires now to be anxiously pressed, as the increase of our privileges will proportionally increase our responsibilities.

Before proceeding to another subject, I may express the hope, that our County Surveyors, a body of officers whom I consider to be our advanced as well as our rear guard, and who have so many opportunities of adding to our knowledge, should, or, at least, that many of them should, arise from their lethargy, and not continue so lukewarm, with respect to our success, as they have hitherto been; and that, considering the aid we may expect in questions *bearing on abstract science*, from the distinguished character of our recently elected Honorary Members, we may, in like manner, be indebted for the practical solution of many perplexing problems, to the skill and intelligence of the County Surveyors of Ireland.

I shall now allude to an important and valuable paper, read at the London Institution of Civil Engineers, in November, 1858, by one of our Past Presidents. This paper is entitled, "On the Railway System in Ireland, the Government Aid afforded, and the Nature and Results of County Guarantees, by George Willoughby Hemans, M. Inst., C.E." After some introductory matter, Mr. Hemans refers to Ireland in the year 1836, which, in regard to Railways, he describes as a blank, from the fact that it possessed, at the time, but one line

of about seven miles in length, namely, from Dublin to Kingstown.

He farther observes, that it was towards the end of that year that the well-known Irish Railway Commission was appointed, but I shall not quote Mr. Hemans's opinion relative to that work, as having been, myself, a working member of the Commission, it is not for me, specially, to refer to its value, even at the present time; though I may be permitted to speak from recollection, of the ardour which animated every one of its members, amongst whom I need not omit myself, as, owing to the intimate knowledge which I possessed of every part of the country, and especially of its physical and geological structure, the agricultural value of the soil of its fertile valleys, and the relative commercial importance, and value of the towns through which the proposed lines of railway would pass; and being requested, by my brother Commissioners, to indicate the course of the intended main trunk lines, I was enabled to lay down with facility, on the map of Ireland, those which were ultimately approved of by the Commissioners, namely, from Dublin to the north, north-west, and south; and it is remarkable that only trifling variations were afterwards made, from the lines which I thus hastily indicated, by the Engineers employed by the Railway Commissioners, namely; Mr. Charles Vignolles, who surveyed in detail, the southern, and Sir John MacNeill, the northern lines of railway.

As it may be desirable that I should enter more at length upon this subject, I think I cannot introduce it more effectually, than by a quotation from the Report of the Railway Commissioners, which is as follows:—

"First, then, we are of opinion that the main line to the south-west, should pass near Maryborough; there, or a little beyond it, throw off a branch to Kilkenny; thence continue its south-western course, through a very easily traversed country, by Thurles, to Holycross; there

throw off a second branch to the right, which, sweeping close round the Keeper Mountains, should run through the rich district of the Golden Vale, to Limerick; while the main branch, continuing its course through Cashel, and winding round the base of the Galtees Mountains, close by Cahir, should pass through Mallow, to Cork.

"At Mallow the line will be within 40 miles of Killarney; and when it is borne in mind how much the profits of a railway depend on the conveyance of passengers, and how great, in all probability, would be the resort to that celebrated spot, of the class of passengers seeking recreation or pleasure, when London shall be brought within 20 hours of Dublin, the importance of such an approximation to Killarney becomes obvious.

"There is yet another strong reason for selecting Cork as the terminus of the great south-western line; if a frequent and regular steam communication with America, from Great Britain or Ireland, shall be established, it appears to us that Cork, either as a steam packet station or as a port of call, would be the most suitable. We merely advert to this important subject here, as we shall have occasion to return to it in a subsequent part of our Report. It will also be observed, that this line would much facilitate the intercourse between Galway and Dublin. The distance by the present coach road is 132 miles, and the journey is performed in 14½ or 15 hours. The proposed railway would enable the traveller to reach Borris-in-Ossory, a distance of 65 miles, in 3¼ hours, when he could complete his journey to Galway by Portumna, a distance of 74 miles, in 8 hours, being a saving of time of 3¼ hours, and travelling only 7 miles more than by the present mail coach road. As part of the same combination, Limerick should be connected with Waterford by a branch crossing a little to the south of Golden, and passing through Clonmel and Carrick, to Waterford; and thus a railway communication would be complete between the towns of Dublin, Cork, Limerick, Waterford, Kilkenny, Clonmel, Tipperary, Cahir, Thurles, Mallow, Maryborough, &c.

"Second, with respect to the northern districts, we are of opinion, that the main line should run to Navan, whence a branch might be easily carried, by Kells and Virginia, to Cavan and Enniskillen. From Navan, the main line, continuing its course to the north, should pass by Carrickmacross and Castleblayney to Armagh, and thence to Belfast."

As the foregoing quotation contains only an outline of the recommendations made by the Commissioners, it may,

perhaps, be interesting to refer to them more in detail, by pointing out on my geological map of Ireland the reasons which induced me to adopt them in the first instance, and, subsequently, to have the lines indicated laid out in detail by the Engineers employed.

The great extent tinted blue on the map, which occupies an area of more than two-thirds of the country, represents the position of the carboniferous limestone series of Ireland, which, with the exception of a small portion situated to the north of lough Allen, in the counties of Sligo and Leitrim, presents the character of a nearly horizontal table-land, which, in consequence, is peculiarly adapted to the cheap construction of either common roads or railways; and hence, on first indicating the lines of railway on the general map of Ireland, which appeared to me to be most desirable, to the north and south, I confined these lines as far as possible within the limits of the limestone country.

Thus in looking to the south and south-west, I took the valley of the Liffey, consequently following nearly the line of the Grand Canal, from Dublin to its summit level, which is elevated about 280 feet above the low water mark in Dublin Bay. From this point the level limestone plain continues in a south-western direction to Maryborough and Templemore, and thence to Holycross, being bounded on the north-east by the Slieve Bloom Mountains, which extends from thence to the Keeper Mountains, in the county Limerick, and form a range of about 50 miles in length.

These mountains consist, not of limestone, but of beds of the old red sandstone, which rise up from beneath the limestone, and rest unconformably upon the subjacent silurian strata, which become visible at various localities adjacent to the more elevated mountain summits.

From Holycross, where the branch railway to Limerick was proposed to commence, the main Cork line was conducted

across the limestone valley, by Cashel to Cahir, which is situate at the eastern extremity of the Galtees Mountains, and thence in a south-western direction it passed through the fertile limestone valley situate between the Galtees and Knockmeildown Mountains, by Mitchelstown and Kildorrery to Mallow, the above mountain ranges being of similar geological composition and character to those of the Slieve Bloom group.

The line of the Great Southern and Western Railway, as actually executed, as far as Maryborough and Holycross, nearly corresponds with the line first indicated by me, with the exception of a slight divergence to the east, about 30 miles from Dublin, which thereby passes through the Curragh of Kildare, but at a higher level than that of the line approved of by the Railway Commissioners; but, from the line forming a nearer approach to the limestone valley of the River Barrow, I am of opinion that the alteration made by the railway company was an improvement. The valley of the Barrow occupies the low ground, bounded on the east side by the granite district extending from Dublin Bay to Brandon Hill, in the county Kilkenny, and on the west by the high ridge of the Kilkenny coal district, the beds of which form a high table-land, resting on the limestone.

From Holycross, the point of divergence from the main Cork line towards Limerick differs materially, and in my opinion not advantageously, from that adopted by the Railway Commissioners.

As already observed, it was proposed by the Railway Commissioners that the main Cork line should pass from Holycross through the towns of Cashel and Cahir, and thence by Mitchelstown to Mallow. The line, as executed, passes from Holycross by Tipperary, from whence it diverges to Limerick, forming a right angle, and thence extends in a south-western direction to Charleville, and skirting the western

extremity of the Galtees and Ballyorra Mountains, it continues to Mallow.

We now return to the Commissioners' line from Holycross to Limerick, which, skirting the southern base of the Keeper Mountains, was considerably shorter than that adopted by the railway company; and the main line itself, passing by Cashel, Cahir, Mitchelstown, and Kildorrery, to Mallow, is also shorter than that actually executed, while, as it passes through more important towns than that by Charleville, I am of opinion that it would have commanded a greater number of passengers and general commercial traffic than does the present line.

In regard to the northern lines, there is a very great difference between those approved of by the Railway Commissioners and those executed by the railway companies; and the following remark is made by Mr. Hemans in regard to them:—

"The lines actually constructed, however—more especially in the northern district—are widely different from those suggested by the Commissioners, and the railway interest has suffered accordingly. There are already two trunk lines to the north instead of one, and a third is in contemplation."

The object proposed by the Railway Commissioners was to adopt, as far as possible, lines which would probably secure the greatest amount of passengers and commercial traffic that the country could afford, and in consequence, they rejected the coast line; and having adopted the interior as presenting two sides instead of one, they recommended that the northern main line should cross the River Boyne at Navan rather than at Drogheda. At Navan the main line was necessarily obliged to leave the flat limestone country, and enter upon that of the lower silurian schists; but it was so selected as to pass through the insulated carboniferous limestone district of Ardee and Carrickmacross, from which, in proceeding northward, it became necessary again to en-

counter the hilly schistose silurian country, over which the line was continued by Castleblayney and Monaghan, to Armagh, and thence to Belfast, according to the line which has since been adopted by the Ulster Railway Company.

At Navan, a branch line suggested by me, and adopted by the Railway Commissioners, was laid out in the limestone valley of the River Blackwater to Kells, whence, crossing the silurian strata, it proceeds north-westward by Virginia, Cavan and Lisnaskea, to Enniskillen. A portion of this line, from Navan to Kells, has been executed in continuation of the Boyne Railway from Drogheda, but it has not been extended beyond Kells.

In other parts of the district the railways which have been executed, though not recommended by the Railway Commissioners, are so well known that it is not necessary that I should mention or discuss them here, my only object, at present, being to state the grounds upon which the Commissioners acted in suggesting the lines recommended by them.

I should wish now to offer a few observations relative to the western line of railway extending from Dublin to Galway, respecting which Mr. Hemans remarks, that:—

"One of the lines, the '*western*,' the construction of which was subsequently entrusted to the author, and which is now very prosperous, paying a dividend of 5 per cent., was repudiated altogether by the Railway Commissioners—saying, it could not be attempted without ruin to the speculators, and a repetition of that disastrous competition, which, in the case of the two canals, has caused a loss of about two millions of money."

It may be observed, that although Mr. Hemans does not positively attribute blame to the Railway Commissioners, for giving their decided opinion that the line of railway from Dublin to Galway would not be remunerative, yet he implies it, by the omission of reference to the principle of calculating the increase of traffic—consequent on the construction of

railways, laid down in England at the time, namely, by multiplying the ascertained traffic, then existing, by three; and this was the principle adopted by the Commissioners.

With a view of obtaining satisfactory results in this respect, relative to Ireland generally, the Railway Commissioners instituted a very detailed and accurate system of ascertaining the amount of the traffic then in existence, both as regards passengers and goods, in the lines of all the railways proposed by them, between the metropolis and the several towns through which each was proposed to pass.

For this purpose enumerators were placed, in every case, for a considerable period, on all the roads at the entrance of all the considerable towns, as well as at the turnpike gates of the post roads leading to each of the towns, and the results thus obtained throughout the country, having been analyzed with great care, were engraved on one of the numerous statistical maps of Ireland which accompanied the railway report.

From the data thus obtained, it appeared, that three times the amount of the traffic, ascertained to be carried on in the line of the proposed railway between Dublin and Galway, would be quite insufficient to repay the interest on the expenditure required to execute the least expensive design for a railway to be formed between those points; and the Commissioners, in consequence, gave it as their opinion that the line should not be undertaken; but they reported, as a resource, that the least expensive mode of communicating by railway, between Dublin and Galway, would be by a branch from the main southern trunk line, commencing near Borris-in-Ossory, and extending by Roscrea, Parsonstown, Portumna, and Loughrea, to Galway.

As a verification of the accuracy of the principle acted on, for the purpose of ascertaining the probable increase of traffic arising from the construction of railways in Ireland, I may

mention, that about four years after the completion of the Ulster Railway, between Armagh and Belfast, the traffic of that line corresponded, very nearly, with triple the amount of the enumeration published by the Railway Commissioners.

The foregoing principle, so universally adopted at the time I speak of throughout Great Britain, was, no doubt, much under the mark, as has since been proved by experience; but fortunately for the Railway Companies *it was so;* as, owing to the fact that the expenditure, actually incurred in completing the railways, has been, in many cases, nearly double of that estimated by the Railway Commissioners, none of the Irish railways would have been remunerative, which will appear by the comparison instituted by Mr. Hemans.

Thus, he states, that the average cost per mile of the Irish railways actually constructed (though some have been completed for 6 or £7,000 per mile), has amounted to £15,000; while the northern line has cost £18,000 per mile; and the Great Southern, instead of £11,000, the average amount estimated by the Railway Commissioners, has cost double, or £22,000.

With regard to the northern railway, through the Slieve Gullion Mountains, between Newry and Dundalk, considered by the Commissioners, as stated in Mr. Hemans's words, to be "*physically impossible*," though subsequently constructed, I can only say, that such a conclusion was founded upon the report and survey of the eminent engineer under whose superintendence this line was afterwards executed; and its supposed impracticability was quite justifiable from the state of our knowledge then existing in regard to the possibility of carrying railways over lofty and rocky mountain passes, such undertakings necessarily requiring steeper gradients than those adopted at the time.

I have only further to observe on this subject, that I rejoice with Mr. Hemans, as also with the country generally, that

the benefits arising from the execution of the several railways have so far exceeded the estimate made by the Railway Commissioners (in regard to the increase of traffic to be realized upon their enumeration), as to exceed it by six instead of three fold, distinct proof being afforded by such a result of an improvement in the commercial intercourse of the country six times greater than that which existed at the period of the Commissioners' Report; from which we may infer, as a natural consequence, that the prosperity of the country generally must have followed nearly in the same proportion.

There is another subject on which I should wish to occupy your attention for a short time, namely, the local guarantee system, as recommended by the Irish Railway Commissioners. The main trunks, and other principal railways of Ireland, may now be considered to be either completed or in progress towards completion, and the lines remaining to be undertaken must consist chiefly of branches connecting neighbouring market towns with the main lines. Such undertakings will, however, *rarely* hold out sufficient inducement to the shareholders of the principal railways to execute them *as profitable speculations*, at least in the first instance, and, in consequence, they must be chiefly carried out by the resident proprietors who are directly interested, with possibly the aid of local guarantees, payable by instalments in ten years, on the part of counties, or baronies within counties through which they would pass, as a security for advances made from the Treasury; and much advantage might have been, and may still be, derived from acting on this principle; but unfortunately it has been much objected to in Parliament, and especially in the House of Lords, which latter has thrown out several of the bills which contained clauses authorizing the treasury to advance loans in aid of much larger sums already paid up by the shareholders, the repayment of which, with interest, was to be secured by county and baronial guarantees.

Our present Lord Lieutenant, when Lord Morpeth, introduced into Parliament a grand scheme, by which the whole of the Irish railways would have been constructed according to the guarantee system; but his proposition was unfortunately abandoned, and in latter times the principle has rarely been successful in Parliament; which is the more to be regretted as the almost unexpected success which has attended several cases, in which the Treasury has been authorized to accept county security, affords sufficient illustration of the benefit likely to result from an extended adoption of the system.

I shall mention an important example, namely, that of the Midland Great Western Extension from Athlone, by Ballinasloe to Galway, which passes through the counties of Roscommon and Galway, for which a sum amounting to £500,000 was obtained by a Government act, on condition of the baronies passed through paying interest at the rate of 3½ per cent., with an additional rate of 1½ per cent. as a sinking fund towards the repayment of the principal; and the traffic of the line to Galway, executed by means of this aid, had produced profits, in the year 1858, nearly equal to the interest charged by the Government; while, up to that period, the sum of £37,414 only had been levied on account of the county and barony guarantee, upon which the before-mentioned sum of £500,000 was secured; and, at the present time, the surplus revenue, exceeding expenditure, more than covers the guaranteed instalments, besides £4,000 remaining in hand to make good any important casualty which may arise.

Another example is afforded by the advance made by the Treasury on the security of certain baronies of the counties of Cork and Kerry, through which the junction railway between Mallow and Killarney passes.

The loan guaranteed amounted to £100,000, in addition to the subscribed capital of £120,000; but objection having been taken to the baronial guarantees subsequently to the passing

of the act, additional security was demanded from some of the principal shareholders; which, having been obtained, the money was advanced; but owing to the success, which from the first attended this railway, the surplus receipts, over and above the working expenditure, was found sufficient to pay the Treasury instalments, and no demand has ever been made either on the baronies guaranteeing or on the shareholders.

I shall also allude to a third instance, namely, that of a guarantee for the sum of £50,000 accepted by the treasury, to be expended in constructing the railway between Killarney and Tralee, in the county of Kerry, on the security, not of the baronies passed through, but on that of the Killarney Junction Railway.

The railway to Tralee has only been lately completed; but I understand that, within the first year, not yet terminated, the traffic on it will probably be sufficient to pay the instalments due over and above working expenses.

Here, then, we have three examples of railways borrowing money from the Treasury on guarantees—two of which have proved to be successful, with every probability that the third will be equally so; and it is to be anticipated that this circumstance will induce the Legislature, in future, to look with a favourable eye on such securities, especially as regards branches connecting the present main trunks, and other principal lines of railway, with neighbouring market towns of importance.

I have now, gentlemen, to make a few observations on a probable source of employment to be derived through the medium of the tramway system authorized by the Treasury act of last session.

The adoption of the tramway system is certainly a move in the right direction, which, if carried out prudently, may prove of great advantage to this country, by affording cheap

branch connexions between important market towns and the nearest railway stations, the tramways being laid down, according to circumtsances, partly along one side of the existing country roads, and partly by special lines opened for the purpose.

No doubt you are all aware of the principle according to which tramways are to be authorized and constructed; that the promoters, having obtained a report of the scheme from the county surveyor, may apply at the summer assizes to the grand jury in order to legalize the undertaking, for which, on full consideration, they are empowered to grant a conditional sanction; but all parties objecting have the power of appeal to the Lord Lieutenant and Council, who shall inquire into the grounds of objection, and allow or disallow such appeal, the application of the promoters in the former case being deemed to have wholly failed.

On the provisional approval of the grand jury, the Board of Public Works are required to hold *a local public inquiry*, and to investigate the merits of the project, on which they are authorized to report their opinion, and recommend such modifications—either in an engineering, financial, or other respect—as may seem to them to be desirable.

At the following spring assizes the grand jury shall take into consideration the report of the Board of Public Works, and any further report which may have been made by the county surveyor, and the grand jury shall then either finally approve or disapprove of the undertaking; but the power of making a second appeal to the Lord Lieutenant and Council is still open to any objectors.

Should there be no valid appeal, the Lord Lieutenant and Council shall take the necessary steps to procure an act of Parliament to confirm the favourable decision which has been arrived at, the bill for this purpose being introduced before the first of June; and, as it is to include all the tramways

which have been approved of during the year, it will be treated as a public act.

This bill would probably not receive the Royal assent before the month of July or August following; hence it would appear that at least a year and a half would elapse from the period of the provisional approval of the grand jury until the work could be commenced.

But, though such delay might be injurious in some cases, still the advantages which a private company will, on the whole, derive by the power of laying down their rails, in most cases along one side of a public road the property of the county, will be very considerable; and, as the rails laid down will belong to them, they must necessarily have an implied, though not a legal, possession of that portion of the road, it being necessary that they should at all times be empowered to repair the rails, bridges, gullets, &c., of a portion of such road, whereby they will frequently, at least partially, interfere with the public traffic on the road or street along which a tramway may pass.

In regard to the construction and working of the tramways, the County Surveyors of Ireland will naturally be much, if not exclusively employed, and it will behove them to consider the peculiarly delicate position in which they will be placed.

At present we must view the County Surveyors as the conservators and guardians of all the public roads and streets within their respective counties, it being their duty to prevent any injuries or nuisances occuring or remaining on them; now, when in conjunction with that paramount duty, they become probably the Engineers in charge, or conductors and maintainers of tramway-works, the double duty may occasionally place them in a dubious, and even in an antagonistic position, as the works which it may be necessary to execute, in constructing or maintaining the tramways, may interfere with, and encroach, for a time, on the public highways; also, under

their guardianship, in consequence of which it will be necessary that they should adopt measures to ensure the greatest strictness, as well as rapidity, in the execution of all tramway-works, so as to avoid complaints, and perhaps jealous murmurs, respecting obstructions injurious to the public traffic, arising from delays in removing the materials left on the roads during the progress or repairs of the works; but in all such cases the County Surveyors will, in my opinion, have but one alternative; and I can only advise them to consider the public roads as the objects of their first love, and not to let the second interfere, in any degree, with their original duty.

I have now, gentlemen, I fear, at rather a tedious length, gone through the several subjects, which, as appeared to me, it would be desirable to bring before you; and though, for the most part, they have been of a general character, they will yet, probably, possess some value as regards our individual interests as Civil Engineers, especially as they are all directly connected with our own country, in which, I may be permitted to observe, I have myself long laboured (and I trust not unsuccessfully) in various departments of the public service; and I still hope to continue those labours, as long as the Almighty gives me ability to do so.

[13th March, 1861.]

M. B. MULLINS, Esq., Vice-President, in the Chair.

On the River Vartry *as a* Source *of* Water Supply *for* Dublin.—By Richard Hassard, Esq., Member.

A new and improved water supply at high pressure, for the city of Dublin and suburbs, has, for some years past, been daily becoming a matter of more vital necessity, and a question of much public discussion; and the corporate authorities

have, from time to time, invited communications from Engineers and other professional men to assist them in selecting a source suitable for the requirements of the metropolis.

I, amongst other Engineers, have devoted a good deal of time and attention to this matter; and having had some experience elsewhere in the water supply and drainage of towns, it has occurred to me that a paper on this subject might possess some interest for the members of the Institute, from the circumstance of this particular branch of engineering having been practised as yet but on a limited scale in this country, as well as from the fact of a scheme projected and designed by a member of this Institution having received the commendation of the Royal Commissioner in preference to those put forward by the most eminent practitioners, in England, of this department of civil engineering.

The first question to be considered was the quantity of water which would be required, or which it would be prudent to procure, not only for domestic use and sanitary purposes, but also for the various trading and manufacturing requirements which exist more or less in every large city.

It appeared to me also essential, that any scheme for the water supply of Dublin should be so laid out, in the first instance, as to admit hereafter of its easy extension, and of a larger quantity of water being then procured in case the requirements of the city increased, so as to demand an additional supply.

The population of Dublin and the suburbs may be taken at 350,000 inhabitants, and the quantity of water requisite or advisable to provide daily for a large city, is not now usually taken, to include all purposes, at less than 25 gallons per individual of the population. This may appear a large quantity, and would probably, at first, be in excess of the demand; but experience has shown that it is not safe to reckon on a smaller consumption. I considered, therefore, that it would

not be desirable to provide, in the first instance, a less quantity than 10,000,000 gallons per day, so as to provide for an addition of 50,000 to the present population, with the facility of increasing it afterwards to 12,000,000 gallons daily, at small cost; and, moreover, that this quantity of 12,000,000 gallons daily should, at any future time, be capable of being considerably increased, should it become necessary to do so; as it has been found elsewhere that it is scarcely possible to limit the consumption of pure water when it can be supplied and distributed at moderate cost.

It became necessary, therefore, to look for a drainage area of sufficient extent to admit of the collection and distribution, for town consumption, of a quantity of water of 12,000,000 gallons daily, at a sufficient altitude to ensure high service—say not less than 200 feet above low water—and also to admit of a further quantity of about 6,000,000 gallons daily being collected, drawn off from the reservoirs, and passed down the streams for compensation to parties below. Experience and litigation having elsewhere pretty well established that about one-third of the available quantity of water passed daily, throughout the year, down the streams, is equitable compensation in kind for the two-thirds collected and otherwise made use of. By this mode of compensation, the volume of water in the streams below is kept uniform throughout the year, floods are controlled, the miller or manufacturer can utilize all, and none need run to waste, and compensation to one party suffices for all.

The total quantity required for supply and compensation, or which it might be desirable to have the means of procuring, would, therefore, be 18,000,000 gallons daily.

At no great distance to the south of Dublin, there exists a tract of high mountain-land, the northern and western slopes of which drain into the rivers Dodder and Liffey; and from this district, no doubt, a very large quantity of water can be

obtained; but, independently of the serious question of interference with numerous mills, manufactures, ornamental property, and water privileges of various kinds, I was, and am of opinion, that the existence of vast beds of dense living peat, on the elevated portions of the drainage areas of the rivers Dodder and Upper Liffey, presents a serious objection to making use of those waters for the supply of Dublin, provided that better water can be procured elsewhere at reasonable cost; indeed, I am of opinion, that for a great portion of the year, the water derived from these sources, although soft in quality, would, from its colour, be objectionable and inferior as a potable water—certainly, so far as regards taste and appearance—to that derived from the canals, if the latter were drawn off at a high level, and at some distance from Dublin, by which many sources of pollution would be avoided; filtration would, however, be necessary in either case, and the quantity of water which the canals could give, as a preferential supply, appears to be too small to render it advisable to rely on them alone; and the cost of constructing works to ensure a supply from the canals, combined with any other source, added to compensation, and the rental to be paid to the canal companies capitalized, would not give the canal projects any appreciable advantage on the score of economy over other schemes which have been put forward.

I am aware that it has been stated, and strongly urged, by Mr. Bateman, who brought forward a scheme for supplying Dublin with water from the Upper Liffey, at Ballysmuttan, that by adopting the separating system—that is, by erecting contrivances on the streams, so that the water, when comparatively pure, would run into a reservoir for town supply, and, when turbid or swollen by flood, into another reservoir for compensation—an abundance of pure water can be obtained from this district; and Manchester has been cited as an example of a city deriving its supply from a district largely covered with

peat, in which this system of separation has been practised with success, and carried to great perfection.

With all deference for so high an authority, I beg to remark, that the geological features of the two districts are totally dissimilar, the drainage area of the Manchester works being sandstones and mill-stone-grit, producing, from its absorbent properties, a large quantity of spring water; it is intersected by a number of valleys, having steep, precipitous sides, covered generally with ferns, scanty herbage, and coarse grasses mixed with heath—being, in fact, a hill district, largely used for pasturing sheep.

It is true that the ridges lying between the valleys are, for the most part, capped with peat, but of a very different nature from the deep beds of sponge-like living peat forming the drainage areas of the Dodder and Upper Liffey.

The peat on the drainage ground of the Etherow, in the valley of which river the Manchester works are situate, is, comparatively speaking, dry sapless vegetable matter, rugged and torn by the storms of centuries, which, apparently, have deprived it of all vitality, and each heavy rain washes away and carries with it into the valleys more or less of this dried peat, like turf-mould or snuff; and to such an extent does this take place, that it is usual in those districts of Lancashire and Yorkshire to construct a smaller reservoir, locally termed a *residuum lodge*, immediately above the main storage reservoirs, for no other purpose than of intercepting by deposition, this finely comminuted peat. The Manchester Water Works, in common with others in the district, have a residuum lodge for this purpose, and the deposited peat is removed from it as occasion requires.

I am tolerably well acquainted with the Manchester Works, and have deliberately arrived at the conclusion that the system which is practised there would be inapplicable to the drainage areas of the Dodder and the Upper Liffey; and that

if pure water for the supply of the metropolis is to be procured by gravitation it must be sought for in some district of sufficient elevation not draining into the Dublin Basin. It occurred to me that if it could be procured from the eastern slopes of the mountain range lying south of Dublin, and conveyed from thence, by pipes or aqueduct, to the metropolis, supplying, in transitu, the maritime suburban districts of Bray, Killiney, Dalkey, Kingstown, Blackrock, &c., it would be the most desirable course to adopt, as the drainage areas of the streams there are free from peat and contamination of every kind; the water is of remarkable purity, and the streams themselves are unoccupied by mills or manufacture; and it is only reasonable to suppose that a revenue would be derived from the supply of the fashionable and wealthy maritime district on the south side of Dublin Bay (now dependent on wells and water collected from the roofs of houses), which, if capitalized, would repay, or partly repay, the additional cost of procuring pure water from this more distant locality.

The idea presented itself to my mind several years ago, and the River Vartry was first publicly proposed by me as a suitable source for the supply of Dublin and the adjacent maritime districts, in a communication addressed to the Pipe Water Committee (then seeking information on the subject), on the 13th October, 1854.

Mr. Hawksley was subsequently employed by the Corporation to investigate the various schemes put forward by different projectors; and on the 23rd August, 1858, I accompanied him and Mr. Neville over the Vartry district, and personally pointed out to those gentlemen the sites of the reservoirs and other works which I contemplated; and on the 3rd September following, I forwarded to Mr. Hawksley in London, plans, estimates, and descriptive particulars of the project, which latter will be found at page 152, Appendix No. 31, of the Commissioner's Report, and which, with copies

of the plans then furnished, I have now the honour to present, with this paper, to the Institute; the estimates I purpose referring to in detail presently.

Mr. Hawksley has since repeatedly, both to myself and others, expressed himself in terms of high commendation as regards the Vartry scheme and works generally, as projected and designed by me.

The following is a brief description of the drainage area, and the data on which the calculations of the water-producing capabilities of the district and storage of the reservoirs were based:—

The area unwatered by the river Vartry, above the Devil's Glen, is well adapted for affording a large supply of the purest possible water; the area of drainage is about 26 square miles, or 16,640 acres; its altitude varying from 600 to 2,384 feet above the sea, the mean elevation being probably 1,000 feet above low water.

The geological formation is, for the most part, cambrian rock; the whole area is a clean pastoral district, almost entirely free from peat, and there are excellent sites for the construction of large impounding reservoirs, which may be made at moderate expense, of sufficient capacity to store and utilize all the water which can reasonably be expected to be collected from the district.

No rain gauges, so far as I am aware, have been placed in the locality; but the records kept at Dublin for many years past will, conjointly with observations taken in the hills adjoining, enable a safe estimate to be made of the quantity of water which it will be possible to obtain.

The average rain-fall in Dublin, from the Ordnance Office gauges, for the 16 years from 1837 to 1852 inclusive, was 29·08 inches; the minimum of those returns being, in 1847, which appears to have been everywhere a very dry year, and during which there fell in Dublin 24·04 inches of rain only.

The estimates of rain-fall on any elevated district, when arrived at only by assuming a certain increase due to the elevation over that of any other neighbouring district where observations have been made, must necessarily be, to some extent, empirical; in this case, however, we are not dependent on calculations of this nature.

Rain gauges were placed by Mr. Bateman, at the commencement of 1860, in the hills adjoining the collecting ground of the Vartry, draining to the site of his proposed Ballysmuttan reservoir, and kept there for a period of six months, during which time observations were made on them simultaneously with others placed in Dublin, in order to ascertain the increase of rain-fall due to the greater elevation of the district.

By these observations it appears that in Dublin, from the 23rd February to the 21st August, 1860, both days inclusive, the rain-fall in Dublin was 17 inches, whilst at Ballysmuttan, on the site of the proposed reservoir, at 750 feet above the sea, it was 27·65 inches, being an increase of more than 60 per cent.; on the higher parts of the drainage area, where rain gauges also were placed, it increased to more than 70 per cent.

As Mr. Bateman very properly remarks, these observations are not sufficiently extended for strict accuracy; but they are, nevertheless, sufficient to show that an amount of rain varying from 60 to 70 per cent. greater than what falls in Dublin may be taken safely as being precipitated on the hills above Ballysmuttan in the same period of time. I take the increase at 60 per cent.

The collecting grounds of the Ballysmuttan and Vartry schemes are only three miles apart at one point, and the distance of their drainage areas from centre to centre, is only eight miles; as regards elevation and general particulars (if we except peat,) they are pretty similar.

The Vartry collecting ground is, however, a little to the eastward of that of the Upper Liffey, and some small deduction should be made on that account.

To place the question beyond cavil, I take the Vartry rain-fall as two-thirds only of that at Ballysmuttan, or 40 per cent. above that of Dublin. The average annual rain-fall, therefore, in the Vartry Valley will be 29·08+11·62=40·70 inches; and in a very dry year, such as 1847, 24·04+9·61= 33·65 inches.

From this is to be deducted the loss from evaporation and absorption; this varies in similar formations from 16 inches downwards; sometimes, in hill districts, falling as low as 10 inches; here, as the upper portion of the collecting ground is steep, from which the water would flow off rapidly—and, as the quantity of spring water in the lower portion is considerable it may be taken at 14 inches—this would leave 26·70 inches of rain as available in ordinary years, and 19·65 inches in a very dry year, such as 1847.

The quantity of water obtainable will be as follows:—

		Gallons.	
At 24 inches of available rain,		24,823,230	daily.
,, 23	,,	23,788,929	,,
,, 22	,,	22,754,628	,,
,, 21	,,	21,720,327	,,
,, 20	,,	20,686,026	,,
,, 19	,,	19,651,724	,,
,, 18	,,	18,617,421	,,
,, 17	,,	17,583,120	,,
,, 16	,,	16,548,820	,,

being rather more than 1,000,000 gallons daily for each inch of available annual rain-fall.

The reservoirs I proposed were, as regards storage, to be of sufficient capacity to give, in the first instance, a quantity of 10,000,000 gallons daily, for town supply, and 6,000,000

gallons for compensation, leaving the storage for the 2,000,000 gallons additional, daily, for the town supply, to be constructed when necessity for procuring the additional quantity arose.

The capacity of a reservoir to maintain its supply during a period of long continued drought, will, of course, depend on the dry weather volume of the springs and streams in its area of collecting ground.

My own experience in gauging water, in a district of similar formation, and personal observation of the Vartry after long continued drought, lead me to believe that a quantity of ·60 cube feet $=3\frac{3}{4}$ gallons per second from each 1,000 acres of drainage may safely be relied on as the average yield of the stream during a period of severest drought; this would amount to 5,391,360 gallons daily, leaving a quantity of 16,000,000 $-5,391,360=10,608,640$ gallons to be drawn off from the reservoirs daily, for supply and compensation.

The reservoirs I projected to be constructed, in the first instance, were calculated for a storage of 225,000,000 cube feet $=1,406,250,000$ gallons, and would, therefore, suffice, with the dry weather volume of the stream, to maintain a a supply of 16,000,000 gallons daily, for town use and compensation, for 132 consecutive days; and taking into account the content of the service reservoir (80,000,000 gallons), for 140 consecutive days, for town supply, which appeared to me to be sufficient to meet all demands, and provide for all requirements of water which were likely to arise for some years to come.

We have lately, however, had access to the records of rainfall, kept at the Ordnance Office in Dublin, up to 1860, from which it appears that the six years, 1854 to 1859 inclusive, were remarkably dry ones—dry, indeed, beyond known precedent—the average rain-fall in Dublin, for these six years, was 22·84 inches, which would, with 40 per cent. added, give 31·98 inches

as the average rain-fall in the Vartry valley for the same period; and deducting 14 inches, as before, for loss, would leave 17·98, say 18 inches, as available for supply to the reservoirs.

I think, therefore, there cannot exist any doubt of the capability of the district to afford a sufficiency of water, even, during the driest known period.

I should be disposed, however, now to advocate the construction of reservoirs capable of containing about 310,000,000 cube feet, which, with the dry weather yield of the stream, would be capable of affording a supply of 18,000,000 gallons daily, for about 150 consecutive days.

The longest recorded drought of which I am aware occurred in 1851. In Yorkshire, where I happened to be professionally engaged at the time, it extended over 110 days, with scarcely any rain. I am not aware, however, of any drought of that duration being mentioned in the meteorological records of this country.

I have prepared, for the purpose of this meeting, a wall map, enlarged to a scale of 4 inches to the mile, from the plans which I submitted to Mr. Hawksley, which represents the scheme as designed by me, and as subsequently modified by him; it will be seen that the deviations from my plans, which have been considered advisable after mature consideration, have been very trivial—so much so, as scarcely to constitute a difference.

The following are copies of the communications, estimates, and descriptive particulars of my scheme, as laid by me before Mr. Hawksley, when deputed by the Corporate authorities in 1858 to examine into the various projects put forward for the water supply of Dublin:—

"46, Upper Sackville-street, Dublin,
"September 3rd, 1858.

"DUBLIN WATER WORKS.

"DEAR SIR,

"Enclosed you have an estimate of cost, and brief description of the works proposed to be executed in carrying out the Vartry project. I have measured off all the distances, &c., from the 6-inch maps, and you may take this estimate as the correct one.

"I also send you a tracing of the section of proposed line of conduit between Loughlinstown valley and the filters and service reservoir, which I happen to have, and by which you will see that there is no difficulty in constructing covered conduits along the hill sides, as I propose for this part of the project.

"I am sending you, as a parcel, by to-nights mail, the index maps of Dublin and Wicklow, with the works, &c., shewn thereon.

"I have indicated the reservoirs, &c., in the Roundwood valley in the positions they would most probably occupy; the lower reservoir would be for assisting in compensation, and receiving the first rush of a flood.

"I am still of opinion that the cheapest mode of supplying Dublin is from the canals, as shown in documents I sent to the Corporation on October 5th, 1854. The supply was then estimated at 10,000,000 gallons daily; but, as a larger supply seems to be necessary, the filters and service reservoir would require to be larger than I then calculated on; if the lock gates on the navigations were kept in good order below the points from which water would be taken, so as to prevent unnecessary waste, I believe there would be a sufficiency of water, more especially as I find the Royal Canal derives a large quantity of water from the Rathwire river, near Killucan, locking towards Dublin, independently of its supply at the summit from Lough Owel.

"If, however, it is determined on to procure a supply independently of the canals, I believe, from the extreme purity of the water, and the total absence of manufacture on the streams, that the Vartry project will be found the best and cheapest which has yet been proposed for the supply of the metropolis and neighbourhood.

"I am, dear Sir,

"Faithfully yours,

"RICHARD HASSARD.

"THOMAS HAWKSLEY, Esq."

"RIVER VARTRY PROJECT.

"REVISED ESTIMATE OF COST.

"Reservoirs on the Vartry river,	£45,000
Conduit and Tunnel from A to B, viz., 4,840 lineal yards Conduit, @ 42s.	10,164
2,640 lin. yds. Tunnel, @ 80s.	10,560
Tank at B,	200
17,200 lin. yds. Iron Main, 2 feet 6 inches diameter, from B to D, @ 63s.	54,180
10 Valves and Cleansing Cocks,	1,000
4,840 lin. yds. Conduit from D to E, @ 42s.,	10,164
Tank at D,	200
Tank at E,	200
330 lin. yds. Iron Main, 1 foot 6 inches diameter from E to F, @ 33s.,	544
2 Valves and Cleansing Cocks,	100
Tank at F,	200
5,720 lin. yds. Conduit from F to G @ 42s.,	12,012
Filters and Service Reservoir,	24,000
10,560 lin. yds. Iron Main, 3 feet diameter, from G to H, @ 75s.	39,600
6 Valves and Cleansing Cocks, @ £150,	900
For connecting with existing Mains in a manner somewhat similar to that proposed by Mr. Neville for the Dodder scheme,	
900 lin. yds. Iron Main, 2 feet 6 inches diameter, @ 63s.,	2,835
2 Valves and fixing,	80
3,900 lin. yds. Iron Main, 2 feet diameter, @ 50s.,	9,750
4 Valves and fixing,	120
1,760 lin. yds. Iron Main, 1 foot 6 inches diameter, @ 33s.,	2,904
2 Valves and fixing,	50
	£224,763
Contingents 10 per cent. on works of construction—say £150,000,	15,000
Act of Parliament, Engineering, and other expenses,	10,237
	£250,000

"THE FOLLOWING IS A BRIEF DESCRIPTION OF THE PROPOSED WORKS.

"The water is intended to be taken from the Vartry river, on which reservoirs can be formed for supply and compensation to the mills and ornamental property below.

"The area of drainage is about 26 square miles, and the daily average quantity obtainable from this area will be,

At 19 inches of available rain, . .	19,651,725 gallons,
At 20 do., do., . .	20,686,026 do.,

and, as the quantity of spring water is large, being fully 6,000,000 gallons daily, on an average, throughout the summer, the loss from absorption must be trifling, and the latter quantity will, probably, be near the truth.

"Of this it is proposed that 5 or 6,000,000 gallons, as may be considered necessary or fixed on, be daily passed down the stream, and 14 or 15,000,000 gallons abstracted for town supply.

"The reservoirs are proposed to be constructed near Roundwood, where favourable sites exist, and the water for town supply to be drawn off at A on map, at a height of 627 feet above low water.

"From A to B covered conduit and tunnel, falling 6 feet per mile.

"From B to D iron pipes, 2 feet 6 inches in diameter, laid along the high road for almost the entire distance; at C a divergence from the high road may be made, and a fresh point of departure obtained, by which the pressure on the pipes beyond would be materially lessened.

From D to E covered conduit, falling 6 feet per mile.

"From E to F iron pipes, 1 foot 6 inches diameter, crossing the Loughlinstown valley by inverted syphon.

"From F to G covered conduit, falling 6 feet per mile, until it passes under the Dublin and Wicklow Railway at Leopardstown, from thence to G the fall is more rapid.

"From G to H iron pipes, 3 feet diameter, for town supply.

"The figures in red indicate the various heights above low water (Ordnance Datum Line).

"The areas coloured green indicate the maritime districts, which may (as well as Dublin) receive their water supply from the river Vartry project.

"Should it at any future time be deemed desirable, a large additional quantity of water, of great purity, may be obtained from the district draining into the Glencullen river (8½ square miles, coloured red), there

stored in reservoirs, where good sites exist, and from thence conveyed to K, where there are some large springs, and from thence to D, where the water from these sources might be incorporated with the present proposed project.

"To compensate for the water so abstracted from the Glencullen river, and used as driving power at Bray, a reservoir, or reservoirs for compensation may be constructed on the Glencree river, draining a district of 9¾ square miles, coloured yellow, as there are several sites suitable for the purpose to be found in that valley

"RICHARD HASSARD.

"Sept. 3rd, 1858.

"NOTE.—I believe that the sum of £45,000 would admit of the construction of reservoirs to contain 220 or 225,000,000 cubic feet, as the land is of poor quality, and there is abundance of material suitable for the construction of reservoirs on the spot, so that the cost of construction would not be more than £200 per million cubic feet of storage.—R.H."

I have now described, in some detail, the particulars of the Vartry Water Works, as designed by me. The cost of the works, as intended to be carried out, to the public, will probably be as follows:—

Corporation Engineer's Estimate, . .	£300,000
Debenture Debt, ...	72,000
New Pipes, and making good and renewal of works of street service, . . .	78,000
Total, . . .	£450,000

The annual cost will probably be:—

Interest on Capital, ...	£22,500
Casual repair to street piping, collection, and salaries, ...	4,500
	£27,000

which would amount to an average annual charge of 18·51*d.* =

1*s.* 6½*d.* per individual, or 16*s.* 8*d.* per house per annum, taking the houses at 32,500, for an unlimited supply of the purest possible water.

If a revenue be derived from the sale of water for trading and manufacturing purposes, and for supply to outlying districts, or if the capital can be borrowed at a less rate of interest than 5 per cent., of course the cost to the citizens for the supply for domestic use will be proportionately diminished.

In conclusion, it only remains for me to mention that, although my scheme has been recommended by the Royal Commissioner, and adopted by the Corporation, yet my name does not appear in the Commissioner's Report as associated with the Vartry project, otherwise than in an Appendix, although my name is put forward on the Plan accompanying the Report, in connexion with another scheme for taking water from the canals, which I laid before the Pipe Water Committee in 1854; nor have I been entrusted with the preparation of the plans now before Parliament, nor in any way recognized in the matter, although, as I have shown, the Corporate scheme is almost identical with the one put forward and designed by me.

On these subjects I do not at present intend offering any remark, further than stating that the omission of my name from the Commissioner's Report has been the subject of some correspondence, and that I hold letters, both from the Commissioner and from Mr. Hawksley, which will set the question at rest, in case my claims as projector and designer of the Vartry Water Works should, at any time, be disputed.

Whatever may be the merits or demerits of the scheme, I wish it to be clearly understood, by the profession and the public, that I claim its paternity. My name has hitherto been associated with the Vartry in a vague manner, as if I had merely shadowed forth or hinted at the project. I furnished all the plans and documents which I have this evening had

the honour to submit to the meeting, on the faith of the Corporate advertisements, and I trust I have now made it clear, to the profession at least, that my claims to be the projector and designer of the Vartry Water Works are not without foundation.

[10th April, 1861.]

Sir RICHARD GRIFFITH, Bart., President, in the Chair.

DESCRIPTION *of the* CRUMLIN VIADUCT.

By A. M'DONNELL, Esq., Member.

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M. B. MULLINS, Esq., Vice President, in the Chair.

REMARKS *on* BOILER DEPOSITS *and* INCRUSTATIONS.—By ROBERT TREFUSIS MALLET; *communicated through* ROBERT MALLET, Mem. Ins. C.E., F.R.S., V.P. Ins. C.E. of Ireland.

IN presenting to the Institution of Civil Engineers of Ireland the following Translation of M. Cousté's Memoir on Boiler Deposits, by my son, Mr. Robert Trefusis Mallet, now employed as a Resident Engineer upon the Great East Indian Railway, Bengal, it may be desirable to preface it by a brief statement of the principal conditions that affect questions referring to the nature, formation, or prevention of boiler deposits.

The importance of the subject to mechanical engineering, and to the public, cannot be overrated. The efficient exclusion of deposits and incrustations from innumerable land boilers of Great Britain alone, would involve the economization of millions of tons of fuel, the preservation of many lives periodically destroyed by explosion, often traceable to this as one in the train of causes; while, if once perfected in marine boilers, it would revolutionize much of our steam-ship machinery. That such results are recognised as possible, is proved by the fact that more than 70 patents encumber the records at this moment for methods presumed to mitigate, or to prevent, deposit or incrustation in boilers; yet, amongst these, it may be affirmed that there is not even one that fully answers its purpose, while the great mass consist of mere "nostrums" that only prove general ignorance of the conditions of the problem by the inventors and by the public.

I do not, therefore, suppose that any apology is required from me on the part of the translator of M. Cousté's most valuable Memoir, although its first appearance, in its original language, dates some years back; for I am myself aware that, owing probably to its having been inaccessible, except in a foreign tongue, it has remained up to the present time almost completely unknown to British mechanical engineers; yet it contains a rigorous investigation of some of the most important conditions upon which depend the *only* method so far effective for the prevention of boiler deposits, namely, the continuous removal of determinate volumes of the heated fluid, so as to avoid saturation and deposition, whether partial or total.

M. Cousté touches but slightly upon the chemical or mineralogical parts of the subject. He deals principally with its thermic and dynamic relations.

I propose, therefore, to preface this Translation of his Memoir, by passing the former relations very briefly in review, and referring as briefly to some of the modes, patent or otherwise, proposed as remedies, and chiefly dependent on chemical relations.

Exclusive of "mine-waters," or other natural waters mineralized or polluted—and hence everywhere to be shunned for feeding boilers, and therefore rather beside our subject—the natural waters with which steam-boilers are supplied for evaporation may be divided into—1st, fresh-waters; 2nd, sea-water. And the questions for the practical engineer refer to the nature of their solid contents, the causes and order of deposit of these, and to the action of their solid contents upon the boiler.

The primary effects of the solid contents of the water ceasing to remain in solution, as when introduced to the boiler, are—1st, deposition, and, at a further and more or less prolonged stage, incrustation, (*i.e.* the induration of the previously

unintegrated precipitate, whether amorphous or finely crystalline.) And the immediate consequences are—1st, interference with the full functions of the boiler in supplying steam; 2nd, the promotion of its destructive action by the fire and flame of the fuel upon its shell; while the remoter consequence is the danger of explosion induced, which becomes extreme when the deposit is thick and diffused. The destructive reaction upon the boiler again is two-fold. 1st, Mechanical—the deposit or incrustation preventing the free passage of heat to the water through the shell of the boiler, causing waste of fuel and over-heating of the boiler, and interfering, in various constructions of boiler, with the free circulation of the fluid, upon which the rapid taking up of heat by it so much depends.

To treat fully of the last would involve the passing in review a great number of different forms and constructions of boiler, and be quite beyond our scope here. It is enough to say that, obviously, boilers with intricate interior construction, closely placed tubes, and water spaces, &c., will be most liable (*cæteris paribus*) to this injurious result. 2ndly, Chemical corrosion and destruction of the metal of the boiler, due to the action of more concentrated saline matter, soluble and insoluble, and to that of the air and gases of the furnace acting on the metal brought to a higher temperature.

Both effects under this head are modified by the nature of the metal of which the boiler is constructed; and, practically, our steam boilers may be classed as either of iron, or of copper, or of some few of the alloys of the latter. Boilers of iron are most acted on by air and water, and by some of the saline contents of fresh and sea-water when concentrated, while copper boilers (once strongly advocated for marine purposes) are more affected by the oxidized sulphur of the coal and by the ammonia evolved from its combustion, and by the oily acids of the grease pumped into and spread about

the boiler. It should be remarked in passing, however, that when sulphurous fuel is burnt at an intensely high temperature, in direct contact with the shell, iron is acted on with great rapidity, whether with or without internal deposits, and apparently by the direct formation, at the external surface of the iron shell, of successive thin coats of bisulphuret of iron; hence it is that copper fireboxes possess their durability in locomotive fireboxes. There are other and independent reasons for this durability however.

In the class of natural fresh waters, the substances *most commonly* found dissolved are lime, soda, iron, magnesia, potass, alumina, and silica (the relative quantities being *usually* in the order here set down); and, in combination with oxygen, chlorine, occasionally with oxydized nitrogen in the form of nitrates, and carbonic acid.

Organic compounds of carbon, hydrogen, and nitrogen, are also often present. Besides these, natural fresh waters contain air in solution, often with excess of oxygen, carbonic acid, uncombined with solid bases, and more rarely sulphuretted hydrogen.

The analysis of Thames water, by Dr. R. D. Thompson, as supplied by some of the London water companies, may be taken as a type of our common hard waters, receptive, more or less, of putrescible matter, and hence of such as most commonly supply our land steam-boilers.

In this city (Dublin) the well-waters from the limestone-gravel are much more rich in sulphate of lime, which is still more the case in the waters, for example, of the Paris gypseous basin; hence, in so far, the latter are both worse than the London water for steam-boilers' supply, sulphate of lime, forming, in fact, both in land and marine boilers, the most insoluble and intractable portion of any deposit formed.

The solid matters contained in one imperial gallon of Thames water, according to the above chemist, are—

THAMES WATER.

Chloride Sodium, ...	16·00 grains.
Sulphate Potass, ...	2·41 ,,
Chloride Magnesium, . . .	2·10 ,,
Carbonate Magnesia, . . .	0·50 ,,
Chloride Calcium, ...	2·11 ,,
Nitrate Lime, ...	0·07 ,,
Sulphate Lime, ...	3·18 ,,
Carbonate Lime, ...	10·70 ,,
Oxide Iron and Alumina, . .	0·46 ,,
Silica, ...	0·24 ,,
Organic Matter, ...	3·56 ,,
Total, . . .	41·33

A boiler fed with such water (and this is not a remarkably impure one), a locomotive, for example, blowing off into steam 1,000 gallons per hour, would, at the end of 350 hours, if no deposit or solid matter were blown out, or otherwise removed, contain nearly a ton of sediment.

An imperial gallon of water is capable of holding, dissolved, when cold (60° Fahr.), and when boiling in free air (212° Fahr.) the following weights nearly of the more important of the preceding salts :—

	At 60° Fahr.	At 212° Fahr.
Carbonate of Lime, ...	Merely traces.	Merely traces.
Silica, ...	70 grains.	,,
Sulphate of Lime, ...	175 do.	,,
Carbonate Magnesia, . . .	3·25 oz.	,,
Sulphate Potass, ...	10· do.	40· oz.
Chloride Sodium, ...	32· do.	32· do.
Chloride Magnesium, . . .	266· do.	580· do.
Nitrate Lime, ...	500· do.	,,
Chloride Calcium, ...	540· do.	Unlimited.

It will thus be evident that the order of deposition, as the ıter in the boiler becomes concentrated, is:—

1. Carbonate of lime.
2. Sulphate lime.
3. The salts of iron, as basic salts or oxides, and some of those of magnesia.
4. The silex and alumina, usually with more or less of the organic matter.
5. The common salt.

The carbonate of lime sometimes deposits as an amorphous ıss, like hard, fawn-coloured chalk, but much more usually, ›ecially in high-pressure boilers, precipitates in the crysline form, as arragonite (one of the dimorphous forms, of ich calcspar is the other). The sulphate of lime falls as orphous gypsum most commonly, but not unfrequently in all crystals of hydrated gypsum (the water combined in usual proportions, as in those discovered some years ago by › late Professor Johnston of Durham—*Transactions of the 'itish Association*), segregated or coherent, as a hard crust, ich latter forms the worst form of "boiler scale," and when ıng exposed to high temperatures, becomes changed to ıydrite, with the form of crystal and hardness of the natural neral.

Recurring now to marine-boilers, or those fed with sea, salt-water—our second class—we may take Bouillon la 'ange and Vogel's analyses of the ocean-water outside yonne, in the Gulf of Gascony, as a type of sea-water. ıe total saline contents in a cubic foot of sea-water varies, t within limits which, in the ocean and all the great tracks navigation, may be practically neglected. The freshest ter is, probably, that of the Baltic and upper part of the ıck Sea—specific gravity about 1024. The extreme limit saltness is in the water of the Dead Sea—specific gravity 10, nearly.

The following are the solid contents of 100 parts of the water of the Gulf of Gascony :—

Chloride Sodium, ...	2·510
Chloride Magnesium, ...	0·350
Sulphate Magnesia, ...	0·578
Carbonate of Lime and of Magnesia,	0·020
Sulphate Lime, ...	0·015
Carbonic Acid (in solution), ...	0·023
	3·496

The essential solid elements, as regards our subject, are the lime, sea-salt, and magnesia, in combination with sulphur and chlorine; and very often in practice, that which analysis does not show, a vast amount of suspended muddy matter, which is pumped with the water into the boilers, as in the Ganges, Bristol Channel, &c.

In minute quantities, sea-water, however, also contains potass, alumina, and various metals, with bromine and iodine.

The following table, by Berthier, shows the order and the proportionate depositions of solid matter upon concentration by boiling off steam from sea-water :—

100 PARTS				
Saline Matter	A Sea-water sp. gr. 1·0278	B Sea-water concentrated sp. gr. 1·140	C Sea-water concentrated sp. gr. 1·220	D Sea-water concentrated salt, nearly deposited.
Chloride Sodium, ...	2·50	16·00	25·50	20·80
Chloride Magnesium, ...	0·35	0·46	1·07	4·85
Sulphate Magnesia, ...	0·58	0·80	1·48	9·50
Carbonate Lime & Magnesia,	0·02	0·00	0·00	0·00
Sulphate Lime, ...	0·01	0·30	0·00	0·00
Sulphate Soda, ...	0·00	2·65	2·81	0·00
Water, ...	95·54	79·79	69·14	64·85
	100·	100·	100·	100·

Thus, when sea-water is boiled down, so that the water is only about 65 per cent., *all* the salts of lime and magnesia, the whole of the sulphate of soda formed, and a large proportion of the sea-salt have been deposited, and these constitute the tough and hard cake of salt, with imperfect crystallizations arranged perpendicularly to the heated surface—*i. e.*, to the iron shell—that is so destructive and inconvenient in marine boilers.

In the state of concentration of D, the sea-water is a strong brine, with a high boiling point. The elevation of the latter is shown by the following table from Faraday's past experiments:——

Volume of Sea-water	Boiling Temp. at 30° Barometer	Saline Matter in 100 parts	Nature of the Deposit
1·000	214° Faht.	3·0	None.
299	217°	10·0	Sulphate Lime.
102	228°	29·5	Common Salt.

Thirty-seven parts of common salt saturate 100 of water, at all temperatures, if both be pure, according to Fuchs; but when the other saline contents of sea-water are present, 36 parts saturate, at 226° Faht., and 30 parts, at 228°—the loss of solubility *augmenting* with the temperature. Hence 10 volumes of sea-water concentrated to 1, becomes, in fact, saturated brine.

M. Cousté has noticed also analogous facts with reference to the sulphate of lime.

We may now pass briefly in review the several methods that have been proposed or tried for mitigating or preventing these injurious deposits. To attempt to go through these *seriatim*, or even the patented ones only, would be impossible, and a bootless labour. They may be classed, however, under the following heads—and first, as respects *land boilers evaporating fresh waters.*

1st. Filtration of the water—an obvious preliminary that should invariably be adopted when the water contains suspended mineral matter, but which does not affect dissolved salts, for, although long continued filtration and moving contact with solids, such as flint pebbles, will deprive water even of some of its soluble contents, the process carried to this extent is too costly for our purpose.

2nd. The application of collecting vessels to the boiler. These are of two sorts—A, External close vessels, heated by otherwise waste flue-heat, into which the feed-water of the boiler is primarily admitted, and passes thence to the boiler.

The function of such a vessel is, that the lime held in solution as bicarbonate by the excess of carbonic acid dissolved in the water is partially precipitated in the vessel as carbonate; the carbonic acid being driven off by the heat.

This constitutes Brunton's patent for sediment vessels.

It has also been proposed to adopt Dr. Clarke's water purifying process to the feed-water entering boilers, and to precipitate the bicarbonate of lime by adding measured volumes of lime-water, so as to form protocarbonate. However, like all other devices that aim at changing the water by chemical means, it is too delicate in application, and any excess of lime would obviously only add to the evil.

I may state here, upon the authority of my own researches of past years, that the carbonic acid is evolved, and the carbonate of lime begins to deposit, as soon as the feed-water is heated to 190° Fahr.—(*Reports British Association.—Report on Iron Corrosion.*)

B. Internal collecting vessels, proposed by many separate inventors long since, and patented several years ago by Mr. Scott. These contrivances depend upon the fact that the solid matter, when first separated from solution, and floating about in the agitated boiling-water of the boiler, will find a resting place, and will precipitate, *i. e.*, collect, in any part of the

boiler where we may provide for it a quiet spot free from agitation of the water.

Hence, if a narrow-necked vessel, as a bottle or jar, be stood within, or hung up in the water of a steam-boiler, the water, although at 212° within it, does not circulate in brisk currents; and gradually the floating particles, as they pass its mouth, fall into this collecting vessel, deposit, and never return from it. This does, in reality, constitute one of the most efficient means known, of collecting the deposit to one point, so as to preserve the rest of the boiler surface free—comparatively. The loose deposit can be readily removed from the collecting vessel.

To this division belongs also the plan often adopted of putting balls of wood, or brick, or stone, &c., into the boiler, which roll about with the agitated water, and aggregate some of the deposit in coat after coat upon their surfaces. This notion is very ancient, and has been known in domestic life; housewives putting a boy's marble into their tea-kettles with a similar object.

The two methods, A and B, may be combined, and I have in my own practice, found this combination advantageous; an external sediment vessel, heated by waste flue-heat, receives the feed-water, and in it the greater part of the carbonate of lime is left, while internal collecting vessels in the boiler receive the greater part of the remainder in combination with the sulphate of lime. This method also has been patented by Taylor.

3rd. The addition of foreign materials to the water of the boiler, with a view to prevent the aggregation of the particles of the deposit, and their adherence to the water of the boiler.

The substances proposed with this end in view are numerous:—potatoes, oatmeal, bran, sawdust, molasses, coal-tar, charcoal dust, smiths' dust, *i. e.*, finely-divided coke and ashes, coal-ashes, plumbago, soap, tallow, and many others, have been

added, in more or less bulk, to the water in the boiler before closing down the man-lid after cleaning. All of these, and more especially such matters as potatoes, or sawdust, possess some power of subdividing, and making more friable, calcareous deposits, and are not without some use, where much sulphate of lime is present in the water, as they greatly interfere with its crystallization into massive crusts, but their effect is temporary, and all such additions are attended, more or less, with the serious evils of "priming," *i. e.*, water being driven over with the steam into the steam pipes and valves of the engine from the boiler, and with it solid matter, which chokes passages, spoils valve faces, &c., &c. To this class of mitigants belongs the useless and expensive nostrum long in use, "by authority," in the Royal Navy, of coating the whole inside shell of the boiler (in steam ships) with tallow and black lead mixed together, under the notion that it prevented the adhesion of deposited salt. It is believed that this is now discontinued.

4th. The addition to the water in the boiler, or to the feed-water entering it, of chemical agents, intended to render the less soluble salts in the water more soluble, and therefore less capable of forming deposits.

Very many of the nostrums that have, from time to time, been patented with this alleged object, have been incapable of any such action. They have often been educts of chemical or other manufactures, sought thus to be profitably got rid of, and not unfrequently were of a character likely to be highly prejudicial to iron boilers. Thus soluble salts of arsenic and copper have been sold for this purpose. The chief agents that have been proposed with intelligent views, however, have been hydro-chloric acid, more or less diluted; chloride ammonium (sal ammoniac), which constituted the matter of Ritterbandt's patent of 1850 or 1851; and chloride of calcium, an educt of many chemical manufactures. None of these are practically effectual. Hydro-chloric acid is a perilous addition

to any iron boiler, as a very slight excess, when continued, will remove a large proportion of the thickness of the shell of the boiler in solution as chloride of iron.

Sal ammoniac and other soluble chlorides are not free from this risk, for, in presence of organic vegetable matter, iron is capable of decomposing slowly even common salt, and, by a remarkable train of decomposition, producing carbonate of soda, and evolution of free chlorine, which, in turn, reacts upon the metallic iron, and none of these agents have any advantageous action upon water rich in sulphate of lime.

Alkaline solutions, carbonate of soda, and caustic soda, have also been proposed, on the ground of their presence rendering the difficultly soluble salts of lime more soluble, but their action in this way is not marked, and the effect in practice is, that the alkaline water is carried up, more or less, with the steam into the pipes and engine, &c., and acts upon all flanges, joints, packings, paint, &c., as a destructive agent. Besides these, tan-pit liquor, decoction of oak bark, catechu, and various other astringent substances, have been strongly recommended by their several proposers; and, perhaps, strangest of all, dye-woods, and various vegetable colouring matters, constituted the subject of the patent of Johnston of 1838. Of all of which we may safely say, that any other "chip in the porridge" would have been quite as useful.

Lastly we arrive at the methods that have been proposed or adopted, for mitigating or preventing deposits in *marine boilers working with sea-water.*

In order of time, the first of these was the very primitive one of blowing off; that is to say, that the sailing engineer, at stated intervals—fixed by experience—permitted the feed-pump to work an excess of feed-water into the boilers, and then blew them off at the sea-cocks fixed into the bottom parts of the boilers. Thus removing at each operation some of the muddy deposits of saline matter at the bottom cells of the

boiler, and with it, some of the denser and more concentrated brine. Occasionally the order of the process was reversed. The blowing off, preceding the feed in excess, of the average consumption of water in steam, but with the danger of laying bare some of the flue plates when the water was thus lowered. However, like every "rule of thumb" method, and in common with all dependent upon personal care and continuous attendance, this was often perilously neglected; and, in my own early practice as a mechanical engineer, I have known the London Steam Ships come into the Port of Dublin with every "pocket," or side chamber beside the furnaces of their boilers, choked up with one solid mass of salt, that could only be removed by cutting the side-plates out and replacing them. The inventions of Hall and others for producing marine-engines with surface condensation, and hence working with fresh water only, the same water being evaporated over and over again, had, amongst other objects, in view the relief of this great evil; and it is now highly probable that, eventually, this form of engine will be made fully available, and will displace the use of feeding with sea-water.

They failed at first, however, and the invention and perfecting of the boiler-feeding arrangements, known as the brine-pump, and of the salinometer, displaced in all well-provided steam ships the old system of blowing off.

The brine-pump is an adjunct of the feed-pump, and its function is to remove, at each stroke of the engine, a determinate volume of the water withdrawn from that part of the boiler supposed to be most highly concentrated as a saline solution, while the feed-pump supplies in its place a larger determinate volume of sea-water in its natural state. The cold sea-water to be pumped into the boiler is caused to pass through tubes immersed in the boiling saline liquid, being pumped out by the brine-pump, and thus robbing the latter of some of its heat, economizes part of the fuel that would be

otherwise wasted. The salinometer, one of the earliest promoters, if not proposers, of which was Mr. Scott Russell, is, in fact, an areometer or hydrometer, by which the specific gravity of the liquid within the boiler, and at various levels, may be tested. There are various constructions; some, always presenting indications, more or less exact, of the density of the fluid within the boiler; others requiring a certain volume of the hot liquid to be drawn off for trial. All depend upon the common principle of the areometer—the floating or not, of bodies immersed in the liquid, with adjuncts for correction as to temperature, &c.

The brine-pump is often used without the salinometer—still oftener with it, but independently of its necessary control; but in the most complete arrangement, the salinometer itself is contrived so as to regulate the proportion between the volume of water withdrawn and that needed to be supplied by the feed-pump.

This was done on board the Don Juan, as an early example, by the salinometer (in this case, a large copper sphere with considerable buoyancy) acting directly upon the valves of the brine-pumps and feed-pumps. A want of sufficient mechanical power, for complete and trustworthy control, was, however, I believe, always found; and a much better arrangement, although one that I am not aware has ever been before proposed or tried, would appear to be, the adaptation to this use of Dr. Ure's thermostad—making the *temperature only* of the fluid in the boiler, or rather coming through the brine-pump out of it, the rule as to saturation, and causing the powerful flexure of the thermostad bars (which may be quite immersed within the boiler or its pipes) to act directly upon the valves regulating the supply.

It scarcely needs pointing out, that no chemical or other agents, introducible to marine-boilers, are capable of producing the slightest practical effect upon the enormous volume

of water evaporated, and of saline matter in a state to deposit.

If the boiler contain 100 parts of sea-water, and the parts evaporated for steam in a given time be $= s$, and if $n =$ the volume pumped out, in order to preserve the state of saline concentration constant at $a =$ (a fraction) parts of solid saline matter; then as there is 3 per cent. of saline matter in sea-water (in round numbers) when

$$3\,(s + n) = a\,n.$$

The amount of saline matter entering the boiler by the feed-pump, and removed by the brine-pump, will be equal, and in this case the brine-pump must remove

$$n = \frac{3\,s}{a - 3.} \text{ volumes.}$$

If $a = 30$, which is the saturated point for common salt, one-ninth of the feed-water must be removed by the brine-pump, and as $\frac{1}{6}$ the fuel that will convert water into steam from a given temperature, will bring it to 212°, the loss of fuel, by this increased influx of cold water to the boiler, and removal of boiling water will be $\frac{1}{6} \times \frac{1}{9} = \frac{1}{54}$ of the whole quantity, assuming that none of the heat was returned to the boiler, by conduction between the issuing and entering fluids, as explained.

This somewhat crude view of the latter part of our subject will serve to illustrate the main question, to the more complete solution of which M. Cousté's Memoir is dedicated.

TRANSLATION *by* ROBERT TREFUSIS MALLET, C.E., *Great East Indian Railway, of an* INQUIRY INTO THE INCRUSTATION OF STEAM-BOILERS, *by* M. COUSTE, *formerly Pupil of the "Ecole Polytechnique," &c. (from "Annales des Mines,"* 5th Series, Tom. V., p. 69, &c., 1854).

CHAPTER I.

THE IMPORTANCE OF THE QUESTION.

SECTION 1.

THE preservation of boilers from the incrustations which water forms on its evaporation, is a question which has long occupied those minds which are familiar with the wants of industry, and which merits the attention of Government.

The question, important as it in fact is as regards economy of fuel, and the preservation of boilers from its effects, is not the less so in relation to the public safety. It is known that when the heating surface of boilers is covered with an earthy crust which removes it from contact with the water, it transmits heat with difficulty. Various evils arise from this fact—

1st. Loss of fuel: the intensity of the fire being increased, in order to produce the requisite quantity of steam, and, as a consequence, the gas of the combustion escaping by the chimney at too high a temperature.

2nd. Speedy deterioration of the boiler by oxidation from the incrustations.

3rd. When employed on board ship, a considerable loss of useful tonnage, by increase of the store of fuel.

4th. Production of the only danger of explosion, against which prudence and care avail nothing in the management of the boiler, and which exposes the ship to much danger.

The high importance then of industry and steam navigation demands some means of preventing the incrustation of boilers; and if it be true that, thanks to human energy and

intelligence, any problem which presents itself with a character of real greatness or utility, is soon resolved—too much cannot be done to point out the importance of that which is here treated of.

I will not confine myself then to the simple enunciation which I am about to make, of the troublesome effects of incrustation, but I will calculate with the greatest possible exactness, what appears to me the most remarkable of these effects, and, at the same time, the most important and most susceptible of a precise estimate. I proceed to refer to the loss of the fuel.

Section 2.

LOSS OF HEAT DUE TO INCRUSTATION.

No direct experiments have been made, to my knowledge, to determine the loss of heat due to incrustation; there are only certain vague and widely different notions concerning the amount of this loss.

M. Grouvelle (*Guide du Chauffeur*, p. 108) values this loss at from 8 to 10 per cent. In a corn-mill at Bordeaux, the loss of heat due to incrustation has been estimated at 15 per cent. Some remarks made by a maker at Havre, on the consumption of fuel by new boilers, and on that which took place in the same boilers after some days' sail, raise this loss to about 40 per cent. Another maker, M. Cavé, in some experiments made for another purpose, has remarked, that a new boiler, giving 8 kilogrammes (17·640 pounds avoir.) of steam for 1 kilogramme (2·205 pounds avoir.) of pit coal, made a return which diminished to 4 kilogrammes (8·820 pounds avoir.) in proportion as it was incrusted.

Of these different instances, the two last are alone conclusive, because they establish the comparison between the state of incrustation and that of perfect cleanness. The results are concordant; they are otherwise confirmed by the theoretical

calculation, as we are about to see. We may regard them then as the expression of truth, and, consequently value the loss of fuel due to incrustation, at 40 per cent. at least, in those boilers which become covered with thick earthy crusts, whether they arise from the nature of the waters which they evaporate, or from the want of complete and sufficiently frequent cleansings.

THEORETICAL CALCULATION OF THE LOSS OF HEAT DUE TO INCRUSTATION.

Not wishing to advance any assertion without foundation, I shall present the calculation by which I have arrived at a general approximate estimate of the loss of heat due to incrustation. Only so as not to detain the reader, from the essentially practical end of this paper, and not to weary his attention by the consideration of a difficult physico-mathematical problem, I shall here confine myself to quoting the results of the calculation, and I shall give its details in a note placed at the end. I shall do the same with all the questions which I shall have to treat mathematically in the course of this work.

The results of the calculation are as follows :—

1st. The loss of heat increases rapidly with the thickness of the incrustation.

2nd. Representing this loss by the difference which exists between the consumption of fuel in a boiler at a medium state of incrustation, and the consumption which should take place in the same boiler, supposing it to be free from incrustation ; it will be represented for boilers of different designs by the following numbers, which may be considered as the *minima* :—

Watt's low pressure flued, or waggon boilers, (1·25 atmospheres), ...	40 per cent.	In relation to the actual consumption.
Tubular boilers, medium pressure, (3 atmospheres), ...	50 "	
High pressure cylindrical boilers, (5 atmospheres), ...	40 "	
Copper locomotive boilers, (5 atmospheres), ...	40 "	

Section 3.

RELATION OF THE QUESTION TO STEAM NAVIGATION.

It is seen from the above that the loss of fuel due to incrustation is, in general, at least 40 per cent. for the boilers of marine engines (which are almost exclusively on Watt's system) with internal flues. Consequently the mere prevention of incrustation would produce a saving of 40 per cent. in the actual consumption of fuel.

Besides, the prevention of incrustation should produce, indirectly, another considerable advantage—namely, to render possible, in ocean navigation, the employment of steam at a reasonable pressure, and thus to allow of being realized, by the use of expansive steam, a saving of at least 50 per cent. on its consumption which would take place in a low-pressure boiler not incrusted.

In making this last assertion, I only anticipate the conclusion at which I arrive in this paper; in fact, I prove in advance that the employment of steam at an elevated pressure, for ocean navigation in general, and especially in that of long voyages, will be practically impossible, so long as we have no means of avoiding incrustation.

Thus, the bearing of the question which is here considered, is that of pointing out a saving of about 66 per cent. When there are added to this the advantages resulting from a much longer duration of the boilers, from a perceptible decrease of the expense of repairs and stoppages, from a great increase in the useful tonnage of the ships, and from the annihilation of all the chances of explosion, which do not arise from either imprudence or carelessness, one will have an idea, though inadequate, of the importance of the problem of preserving boilers from incrustation.

The question being thus defined, I proceed to develop the work which I have undertaken for its solution.

CHAPTER II.

FORMATION OF THE DEPOSITS.

SECTION 1.

DESCRIPTION OF THE DEPOSITS OF MARINE BOILERS.

To pursue a sure course in my researches, I have considered it necessary to commence by determining the nature of the deposits, and then to recognise the circumstances essential to their formation. To this end I have examined the boilers of several steamers.

The facts which I have observed are as follows:—All the parts of the boiler which are immersed in the water are covered with a whitish crust, with a mammillated surface, as hard as marble, its fracture partly amorphous, and partly crystalline. The thickness of this crust varies much, about 0·078 inches over the fire grate, it is from 0·39 to 0·49 inches on the points of heating surface where the heat is less intense. At the bottom of the boilers a considerable quantity of loose deposit is found, some small and isolated, some conglomerated, and forming concretions, occasionally as large as a stone-chipping.

If the fracture of a tolerably thick crust be examined, while still adhering to the side of the boiler, certain little yellowish veins are perceived, of an earthy and less hard consistence, in the direction of which, the concretion splits easily. The surface of contact with the metal is blackened by a stratum of oxide; proceeding from this face a series of amorphous strata is found, white, and divided by the yellowish veins I have just spoken of, and at the opposite face there is generally a stratum of a crystalline appearance.

If, in like manner, one of the tolerably thick scales be examined, it will be perceived to be often formed of a core of amorphous strata, completely enveloped in a crystalline stratum, more or less thick.

I have chemically analyzed several specimens of the crust. The following are the results for three specimens taken, one from the boiler of the "Hamburg," from the open sea, the others from two tubular boilers of steamers from the Mediterranean:—

Origin of the Deposits	Radical Products							Composition					
	Sulphuric Acid	Carbonic Acid	Lime	Magnesia	Iron and Alumina	Water		Sulphate of Lime	Subcarbonate of Magnesia	Free Magnesia	Iron and Alumina	Water	
From angle of the vertical surface (carneau de la surface indirecte) of the boiler of the "Hamburg" (crust partly crystalline), ...	50·00	1·00	35·20	7·20	...	6·60		85·20	2·25	5·95	...	6·60	
From inside of the tubular boiler of the "Mediterranean" (crust chiefly amorphous,)	50·01	1·04	34·93	8·96	0·41	4·65		84·94	2·34	7·66	0·41	4·65	
From inside of another boiler of the "Mediterranean" (crust chiefly amorphous), ...	47·61	1·42	33·29	12·62	0·50	4·56		80·90	3·19	10·35	6·50	4·56	

Besides the deposits which I have just described, there was found in the boiler, at the bottom, and on the horizontal plates of the heating surface, a muddy deposit, composed in very

variable proportions, of sulphate of lime, free magnesia, subcarbonate of magnesia, traces of iron and alumina, of silica and organic matters.

This mud contains no more carbonate of lime than the concreted deposit, for the lime and sulphuric acid are present in proper proportions for saturating one another.

I lay down from this then the important fact (proving it more fully in note 2 at the end), that the deposits formed in boilers fed with sea-water, be they concreted or muddy, are free from carbonate of lime, a quality which essentially distinguishes them from those which are formed in boilers fed with fresh water.

Section 2.

THEORY OF THE FORMATION OF DEPOSITS IN MARINE BOILERS.

Having established the nature of the deposits by analysis, I had recourse to synthesis for determining the circumstances of their formation, and thence deducing the theory of the phenomenon.

The results of this synthesis are described and explained in Note No. 2, at the end. I have thence deduced the following theory of the formation of these deposits :—

1st. Muddy deposits. After some moments of ebullition, the water in the boiler becomes cloudy, and holds in suspension, first free magnesia, and then subcarbonate of magnesia. These two precipitated in small quantity, are floculent, and have no tendency to aggregate; they form with the organic and earthy matters, which the water holds in suspension, the muddy deposits which are found in the bottom of the boilers, and on the horizontal plates of the heating surface.

2nd. Incrustation. When, in the progress of the ebullition, the water has been saturated with sulphate of lime, this salt

deposits itself in a crystalline crust, adhering to all the surfaces wetted by the water.

We shall see ere long that the incrustation may commence previous to saturation on those parts of the surface which are highly heated, and although the mass of the water be not yet saturated

3rd. Development of the incrustation in strata. When the ebullition is arrested, and the water cooled, a part of the muddy deposit, which the motion of ebullition held in suspension, falls upon the plates of the boiler, or rather upon the crusts which cover them, and this very fine stratum of mud, lodged in the roughnesses of the mammillated surface of the incrustation rests there for the greater part, until the ebullition recommences. Then, if the water be above the point of saturation for sulphate, it forms a second stratum of this salt superposed upon the first; and thus the crust becomes divided by a vein of magnesia and of subcarbonate, with a little oxide of iron, or organic matter, which gives it a yellow colour.

4th. Differences of thickness in the crust. The heat being very intense on the furnace-plates, the evaporation will be very active there, and consequently the deposit will develop itself very rapidly. The crusts then might be supposed to become thicker there than elsewhere, but the contrary is the fact; for, as fast as they are formed here, they are detached by the contraction and expansion which the metal experiences at every change in the intensity of the fire. It is found, in fact, that the crusts which cover the surface here are composed of scarcely more than a single stratum, without a vein showing in the fracture.

On the other hand, the crusts will be thicker on the less-heated points, and will be composed of distinct strata, divided by veins, and generally thinner than the single stratum of the furnace.

5th. Amorphous fracture of the crusts. We have said that

the fracture of the crusts is amorphous throughout almost the whole of their thickness, except at the surface opposite that of contact, where it presents an appearance of crystallization; and we have also said that, of the isolated concretions which are found at the bottom of the boiler, the greater part is formed of an amorphous nucleus enveloped in crystalline crusts.

These facts prove that, at the moment of deposition of a stratum, it has the character of crystallization that is due to a certain proportion of water; but that, after a certain period of contact with the metal, this water of crystallization becomes disengaged, and the crust itself amorphous. Contact with the heating surface suffices to produce this effect, for it is always above 300° cent. (572° Fahr.), and we know that 200° cent. (392° Fahr.), is sufficient to free sulphate of lime from its water of crystallization. It is known from other sources that this anhydration diminishes on receding from the face of contact, and that it is nil at the surface immersed in the liquid, the latter having little more than 120° cent. of temperature (248 Fahr.).

Section 3.

FORMATION OF DEPOSITS IN BOILERS FED WITH FRESH WATER.

All fresh waters, in their natural state, contain bicarbonate of lime; the chief part contain, in addition, sulphate of lime, chloride of calcium, chloride of magnesium, and sulphate of magnesia, these two last salts generally in very variable proportion.

The greater part of the carbonate of lime precipitates during the first moments of ebullition, in consequence of the disengagement of carbonic acid. This deposit generally assumes the muddy form, and gives few concretions.

But a part of this salt remains in solution; in fact, clear water retains from $\frac{1}{24000}$th to $\frac{1}{16000}$th of carbonate of lime. It is this portion then which, on precipitating slowly, and

as the water evaporates, crystallizes and collects to form the concretions.

The same reactions which we have noticed in the case of sea-waters (see Note 2), between the salts of calcium and magnesium, reappear in the case of fresh waters, and tend to diminish the pre-existing quantity of carbonate of lime; but since, in the latter case, the carbonate of lime is very abundant in proportion to the chloride of magnesium which tends to destroy it, the first of these salts is found in the deposit, in contradistinction to what takes place in sea-waters.

As to the sulphate of lime, it crystallizes and concurs in forming the concretion from the moment that the water is saturated with relation to this salt.

It will be understood from this that the constituent elements of these deposits, whether muddy or concrete, will consist either of carbonate of lime alone, or of a mixture, in variable proportions of carbonate and sulphate of lime—according to the nature of the waters whence they proceed.

CHAPTER III.

MEANS OF PREVENTING THE INCRUSTATION.

The industrial world has been engaged for a long time in searching for some suitable means of preventing incrustation in boilers. Many processes have already been tried, and every day the employment of some new chemical substance or other is proposed. But all these processes have failed, and the preceding paragraphs have shown why, this has necessarily been the case.

It is not by the direct action of chemical agents that this incrustation can be prevented; and if any means exist of attaining this end, there are few chances of discovering it except by the examination of those peculiarities which the solubilities of carbonate and sulphate of lime present, since the incrustation is only the crystallization of these salts.

And, in fact, the synthesis given and described in Note No. 2 puts one on the track of means which present some chance of success, and which are founded on the solubility of sulphate of lime in salt-waters.

I have been thus led to study, in special reference to the question which now occupies us, the solubility of sulphate and of carbonate of lime.

The details of this investigation are given in the Note No. 3 at the end. The principal results are:—

1st. Sulphate of lime is less soluble at a high than at a low temperature, both in sea and fresh water.

For temperatures above 100° centigrade (212° Fahr.), the solubility of sulphate of lime in sea-water diminishes almost proportionately to the increase of temperature, and consequently the solubility diminishes very rapidly in relation to the increase of corresponding pressures. The following table shows this solubility for different temperatures, as well as the degrees to which the saturation with sulphate of lime reaches.

TABLE A.

SOLUBILITY OF SULPHATE OF LIME AT DIFFERENT TEMPERATURES ABOVE 103° (217·4° FAHR.)

Degrees of the Areometer corresponding to the Saturation	Temperatures (Centigrade)	Temperatures (Fahrenheit)	Pressures in Atmospheres	Proportion of Sulphate of Lime to 100 of Water at Saturation or Solubility	Degrees of the Areometer corresponding to the Saturation	Temperatures (Centigrade)	Temperatures (Fahrenheit)	Pressure in Atmospheres	Proportion of Sulphate of Lime to 100 of Water at Saturation or Solubility
12·5	103·00	217·40	1·00	0·500	6	118·50	245·30	1·50	0·226
12·	103·80	219·84	1·00	0·477	5	121·20	250·16	1·50	0·183
11·	105·15	221·19	1·00	0·432	4	124·00	255·20	2·00	0·140
10·	108·60	227·48	1·25	0·396	3	127·60	261·80	2·00	0·097
9·	111·00	231·80	1·25	0·355	2	130·00	266·00	2·50	0·060
8·	113·20	235·76	1·25	0·310	1	133·30	271 94	2·50	0·023
7·	115·80	240·44	1·50	0·267	–	—	—	–	—

This table explains, for example, that sea-water being submitted to ebullition under a pressure of one atmosphere, or at 103° (217·4° Fahr.) of temperature, it will be saturated with sulphate of lime when it shall have acquired the concentration of 12·5° of Beaumé, and then it will contain 0·500 per cent. of this salt; at 1·25 atmospheres, or at 108·6° (227·48° Fahr.) of temperature, the water will be saturated with sulphate of lime, when it shall indicate 10°, and will then contain 0·395 per cent. of sulphate of lime; at a pressure of 2 atmospheres, or 124° (255·2° Fahr.) of temperature, sea-water, in its natural state, before receiving any concentration, is very near the point of saturation, for the natural water shows from 3° to 3·5°, and in the last case saturation takes place at 4° of concentration.

2nd. Sulphate of lime becomes completely insoluble, both in sea and fresh waters, at temperatures between 140° and 150° (284° and 302° Fahr.) And if water containing this salt in solution be exposed to these temperatures it completely precipitates in the form of small crystals or thin pellicles, according as the salt is more or less abundant in the solution.

The sulphate thus precipitated redissolves on cooling, but with much greater slowness, as the temperature at which it had deposited was high. That which deposits at 150° (302° Fahr.) takes several days to redissolve, although its proportion in relation to the water is very slight.

3rd. The neutral carbonate of lime is slightly soluble in pure water. This solubility in the cold is, according to Bucholz, from $\frac{1}{24000}$th to $\frac{1}{18000}$. It diminishes in proportion as the temperature increases; and although it diminishes less rapidly than that of the sulphate of lime, it, nevertheless, becomes nil at a temperature of 150° (302° Fahr.); at this temperature the water containing the carbonate of lime in solution abandons it completely; and once thus precipitated the carbonate never redissolves on cooling.

From these facts we shall hereafter draw conclusions.

CHAPTER IV.

PRINCIPLE OF EVACUATION.

SECTION 1.

IN the before quoted synthesis (Note 2), we have seen that for sea-water—

1st. The actual incrusting matter consists wholly of sulphate of lime.

2nd. That this salt only begins to deposit itself when the water has arrived at a certain standard degree of concentration. This degree, evidently depending on the proportion of lime pre-existing in the sea-water, will vary with the origin of this water; but for those of the Atlantic and Mediterranean on our coast it is the same—12° to 13° of the areometer of Beaumé, when the ebullition takes place at the pressure of the atmosphere. It appears then that, to prevent all incrustation in boilers fed with sea-water, it would suffice to maintain the water in the boiler at a degree of concentration below that which corresponds to the point of saturation with sulphate of lime. This could be done *by evacuating the water in the boiler in such a relative proportion to the quantity of water injected, that the quantity of sulphate of lime removed may be at least equal to the quantity of sulphate introduced by feeding.*

That is to say, that P being the weight of water injected in a given time, p that of the water evacuated in the same time, n the quantity of lime contained in the feeding water, N the analogous proportion for water concentrated to saturation with sulphate of lime, it would suffice to make

$$p > \frac{n}{N} P.$$

In order to make this principle applicable it is evidently necessary that $\frac{n}{N}$ should be a small fraction.

This condition is sufficiently fulfilled in sea-water; for (Note 2) supposing that all the lime be in the state of sul-

phate, which may be taken for granted here; it is found (Table A) that natural sea-water, or that of 3° of Beaumé, contains 0·097 per cent. of sulphate of lime; and that this same water being brought to saturation with sulphate, by boiling in the open air, that is to say, being at 12·5° of Beaumé, it contains 0·500 per cent. of sulphate of lime. We have then in this case $\frac{n}{N} = \frac{0{\cdot}097}{0{\cdot}500}$ or $< \frac{1}{5}$.

Let us always remember that (Table A) N diminishes rapidly in proportion as the temperature or the pressure, at which ebullition takes place, increases. It preserves still a great value when ebullition takes place under a pressure of 1·25 atmospheres (109° cent.=224·4° Fahr.), which is the case in low-pressure boilers. But starting from pressures of from 2 to 3 atmospheres (121° and 135° cent.=249·8° and 275° Fahr.), N has values less than n.

As to fresh waters, the principle of evacuation is applicable to them, because, on the one hand they dissolve very little sulphate of lime (less than 0·003 per cent. at ordinary temperatures), and on the other, they always contain some carbonate of lime, against which evacuation will avail nothing.

We must conclude from this that the principle of evacuation is only applicable to boilers fed with sea-water, and again, only to these boilers when worked at a low pressure.

Section 2.

APPLICATION TO MARINE LOW-PRESSURE BOILERS.

In the inequality $p > \frac{n}{N}P$. then we have $N = 0{\cdot}395$, corresponding to the pressure of 1·25 atmospheres, (or 109° cent.= 224·4 Fahr.) of temperature, and $n = 0{\cdot}140$, which corresponds to the concentration of 4°, being above that of sea-water on our coasts, and, *a fortiori*, to that of the feeding water coming from the condenser. We will also have

$p > 0{\cdot}35P$; let $p = 0{\cdot}5P$, in order that we may have a margin, always necessary in a general application. Then by evacuating 0·5, while the supply is 1, it appears that we ought to avoid incrustation.

DEGREE OF EFFICACY OF THE PROCESS OF EVACUATION.

This process is founded on a principle so plainly established that, at first, its success seems perfectly certain. Nevertheless, there exist facts which throw some doubt on its complete efficacy. Thus, in well-found steamers, such as the Great Britain, the Royal William, the Asia, the Franklin, the Humboldt, &c., the engines are provided with pumps of evacuation (*brine-pumps*), and these pumps have a continuous motion. The steamers of the French fleet possess also pumps of evacuation, and, according to the prescribed dimensions, these appendages should extract a quantity of hot water equal to one-half the quantity of water injected. Nevertheless, in all these ships the boilers are subject to very sensible incrustations, if not as great as in the ordinary steamers of commerce.

That this evacuation, however continuous, cannot take place under the conditions to prevent saturation is unquestionable, because the pumps, the only apparatus employed for this end, cannot act with the precision necessary for it, as we shall see before long. It was not the less necessary, to submit the process of evacuation to direct experiment, made under the same conditions under which low-pressure boilers act.

These experiments, the details of which are given in note No. 4, at the end of the Paper, prove that *the process of evacuation is of imperfect efficacy: it prevents incrustation on the surface of* INDIRECT *heating, but it is powerless to protect the surface of* DIRECT *heating.**

* Following the language usually adopted by Mechanical Engineers, I call those parts of the boiler which receive the radiated heat of the fire and the contact of the flame, surfaces of direct heating, and those parts which are only heated by the contact of the smoke and the gases of combustion, surfaces of indirect heating.

Here is the explanation of this important fact:—We have seen that for a given pressure, or temperature of ebullition, the sulphate of lime only deposits itself when the concentration is below a certain corresponding degree. The process of evacuation has for its object, and will infallibly have for its end, the prevention of the water in the boiler from reaching this limit of concentration. But the heat being very intense on the plates which receive the radiation from the fuel and the contact of the flame, the stratum of water which touches the metal at these places, will exceed the temperature of this limit of concentration, and will deposit its sulphate. In fact, some time must elapse before an equilibrium of temperature is established between this stratum and the mass of the water, because this is effected solely by circulation, the conducting power of water being very slight; and it may be that this time is too long, relatively to the rate of transmission of heat through certain parts of the heating surface.

The process of evacuation then is only a palliative to incrustation in marine low-pressure boilers; a valuable palliative it is true, for the indirect surface not being incrusted, the gases of combustion can cool to a point suitable to their (previous) heat, from whence there results the almost entire prevention of the loss of heat due to incrustation, as Note No. 1 proves.

Evacuating apparatus.—It is not useless in practice to perfect this process, although in principle it be incomplete in its efficacy, and confined in its applications.

In order that this process should succeed, it is necessary that the evacuation of the cold water should be made with regularity and precision, for its object is to maintain the water in the boiler below a certain degree of concentration, past which there will be a deposit of sulphate, and, yet to keep the water very near this degree, so as not to needlessly increase the loss of heat.

The apparatus which first suggests itself to realize evacuation

would consist of a pump, whose motion, connected with that of the feed-pump, should be regulated in such a way as to extract a determinate quantity of water at each stroke of the piston. This, in fact, was the means adopted in the experiments described in note No. 4; but difficulties there experienced have induced me to renounce it, and have convinced me that a pump, on whatever system, will never act for this purpose, with the necessary regularity and precision. In fact, the best kept boiler always contains, besides the muddy deposits of magnesia, impurities arising both from the water itself, and from the action of this water on the metal, and on the cement of the joints, &c. These deposits and the other impurities, are partly withdrawn with the water of evacuation, and obstruct the working of the valves, which then do not shut sufficiently close to admit of the regular working of the pump. The apparatus which I propose and describe as follows, is to obviate this difficulty, and possesses all the desired regularity and precision :—

The principal part of the apparatus is a cock C, (Figs. 3 and 4, Plate VI.) permitting the escape of the water from the boiler, and which for this purpose is opened and shut by a regular intermittent movement, produced by the feed-pump. Figs. 1 and 2, Plate VI., represent the half of the engine of a steamer, consisting of, a cylinder, X; the two bodies of the boiler, Y Y; and mounted with the apparatus under consideration. There is represented also the system of Wilson's "refrigerator." (Enlarged over Fig. 5.)

The hot water comes from the two boilers by the tubes *a a'*, and entering the refrigerator by the extremity near *a*, leaves it by the other. This refrigerator has four exterior pipes, of which two receive the water from one of the boilers Y, and conduct it to the cock C, and the other two receive the water from the other boiler, and conduct it to the cock C'. The cock C is moved by the lever E, which commands the feed-pump D by

means of a segment F, fixed on this lever, and which works into the pinion G, mounted on a crank H. This pinion is loose on the shaft, but it acts by a pall, I, on a small ratchet, K, fixed on this shaft; so that at each ascending movement of the pump-rod (of the feed-pump) the ratchet and, therefore, the shaft turn through a certain angle. This shaft, by the pin L, and its connecting rod, communicates its motion to the lever N, and, consequently, to the cock C. The lower extremity of the connecting rod carries a slide, in which the pin of the lever N works, and the length of which can be altered by a moveable stud, which can be made to ascend or descend by means of the adjusting screw. Thus this slide produces in the movement of the cock what is called a "delay," which serves to regulate its amount at each turn of the crank H.

The evacuated water delivers itself into a vessel P, which communicates with the steam in the boiler, by a pipe, so that the flow of this water taking place by the sole effect of difference of level, which does not sensibly vary, gives a constant volume for each turn of the crank H. The desired relation between the water evacuated and that supplied is thus obtained.

The vessel P carries a gauge tube U, which permits of measuring, at will, the volume of water extracted at each revolution of the crank H, and, consequently, of proving the regularity of the process of evacuation.

As soon as the cock C shuts, the cock R opens by means of the levers ST, and allows the water to flow into the sea by the action of the steam through the pipe in the top of the vessel P, and when the cock C has opened again, R is already shut.

In order to note the progress of the evacuation, each boiler carries an *indicator of density* (Salinometer), after Seaward's design. It is a glass tube communicating with the water in

the boiler by its two extremities; it carries two delicately adjusted glass bulbs, so that one shall indicate a density somewhat above, and the other one somewhat below, that which is proposed as the limit. According to the position of these bulbs will it appear proper to increase or diminish the evacuation; and to produce this effect it suffices to cause the screw to push the stop backwards or forwards, for thus the "delay" of the cock C is diminished or increased. Figs. 3 and 4, Plate VI., represent the details of the apparatus on a larger scale.

It is seen that there are two such apparatus, one for each boiler, and for each feed-pump. But since it is always necessary to have a reserve feed-pump, acting when necessary, for either boiler; this pump δ must work alike, when wanted, on the crank H or the crank H′, that is to say, on the cock C or the cock C′. For this end the lever ε carries two segments ϕ, ϕ', working respectively in the two pinions γ, γ', which are fast on the cranks H, H′. These two pinions can act on ratchets μ, μ' by means of palls similar to I; and these palls can be put out of gear by putting the head over the little button a, so that the cock C can be used with the pump D or the reserve pump δ, and the cock C′ either with the pump D′ or with the same reserve pump δ.

Section 3.

EFFECTS OF INCRUSTATION ON HIGH-PRESSURE BOILERS.

Boilers of medium and high pressures, having no resource in the process of evacuation to diminish their incrustations; let us consider in what state they would be found after being some days at sea.

Every cubic metre (35·33 cub. feet) of water carrying into the boiler 1·5 kilogramme (48·23 oz.) of sulphate of lime, of which a considerable part (at least two-thirds, that is 1 kilogramme 32·15 oz.) would form a concretion. If we assume the ordinary extent of heating surface, rate of evaporation,

and density of the sulphate, we find that the crust would augment in thickness at the rate of 0·015 of a millimètre per hour (0·00159 of an inch). Let it be supposed a transatlantic steamer,* and let us assume the most favourable case—one difficult, if not impossible, to realize—that in which the boiler would be completely cleansed on setting out. The voyage being of fifteen days or 360 hours, the crust will acquire during this lapse of time a thickness of $0{\cdot}015 \times 360 = 5{\cdot}4$ millimètres (0·212 inches) uniformly spread, or nearly so, over the *direct* and *indirect* heat surfaces, so that after the fourteenth day the thickness will be about 5 millimètres (0·20 inches).

Could the engines give twenty-four hours' more work with boilers thus incrusted? Or, at least, is this to be taken for their normal working condition? We cannot hesitate to pronounce in the negative, when we compare such a state of things with what actually takes place in low-pressure boilers.

In the present boilers of transatlantic steamers, a continuous evacuation is made use of by means of pumps, which, in spite of their defective and irregular play, do diminish the incrustation, principally on the *indirect* heating surface. This part of the heating surface remains covered with a crust of ½ millimetre (0·019 inches) at most, if there be care taken at each voyage to clean the boiler by the use of the hammer and scrapers. Although incrusted, this part of the surface preserves, relatively, a considerable conducting power; it perceptibly aids the evaporation, and the direct surface has so much the

* Let the engine be of 450 H.P. The heating surface will be 420 square mètres. The evaporation, at the rate of 30 litres per H.P., per hour, will be $30 \times 450 = 13{\cdot}5$ cubic mètres per hour. The weight of the crust formed per hour will be then $13{\cdot}5 \times 1^{k} = 13^{k}{\cdot}5$. Supposing the density of the crust $=2$, the volume of this crust will be $\frac{13{\cdot}5}{2} = 6{\cdot}75$ cubic decimètres. This crust being uniformly distributed over a surface of 420 square mètres will form upon it a thickness of $\frac{0{\cdot}00675}{420} = 0^{m}{\cdot}000015$ or 0·015 of a millimètre.

less to do Consequently, the fire may be less intense; the wear and tear of the flues is less rapid; and the chances of accident are less numerous. Yet, nevertheless, these boilers only resist long voyages with difficulty, and very often the evaporation is so slackened by the eighth or ninth day, as to render it necessary to delay the ship for 12 hours by having to clean the boilers. What would happen then if the *indirect* surface were continually more and more incrusted, so that almost all the work of evaporation should devolve on the *direct* surface, at a great increase of fuel, and entailment of extraordinary excitement of the fires.

We must conclude, then, that unless we have a perfectly efficacious means of preventing incrustation, the employment of high-pressure steam will be practically impossible in maritime navigation; and we must conclude from what precedes that this can only be done by *feeding the boilers with water free from any calcareous salts in solution.*

But how are we to overcome the difficulties which we meet with even in a manufactory, still more on board a ship at sea, in order to procure sufficient quantities of such a water. Three means present themselves, which I have successively examined in tracing the advantages and disadvantages attached to each of them.

CHAPTER V.

PRINCIPLE OF A MONOHYDROUS SUPPLY.

To condense the steam after it has played its part in the cylinder, in such a manner that it shall not mingle at all with the *condensing* water, which is necessarily calcareous, and to feed the boiler solely with this water of condensation. Such is one of the means, which, for shortness sake, I shall call a *monohydrous* supply, because it consists of a supply with one identical quantity of water.

The application of this principle requires the employment

of "surface condensers," the object of which is to isolate the steam from the cold water which is to condense it. I am about to explain these condensers, to show the failure of the experiments hitherto made to bring them into use, and to prove that the monohydrous supply presents obstacles which are insurmountable in the present state of our mechanical resources.

SECTION I.

SURFACE CONDENSERS.

THE different attempts at the construction of this apparatus date back to the time of Watt. Since that, at different epochs, the experiments of S. Hall, Cavé, and John Ericson, with other engineers, have been made. But all these experiments failed from one obstacle—the retardation which the evaporation experiences in all forms of the apparatus.

NECESSITY OF INSTANTANEOUS CONDENSATION.

In order to avoid a loss of power, it is necessary that the condensation of the steam should be instantaneous. This condition is fulfilled in the *ordinary condenser*, where the steam is in immediate contact with cold water, the surface of which is greatly increased by being made to fall in rain in the condenser; whilst in the surface condenser the annihilation of the steam is retarded by the difficulty with which the heat passes through the walls which separate the steam from the condensing water.

This loss of force increases with the amount of delay of the condensation. I have thought it advisable to ascertain the relation which exists between the loss of motive force and the amount of delay; and have treated this question in Note 5. Let us apply the formulæ there obtained:—

Let the first mover be of 450 H.P., in two engines of 225 H.P. each, working at a pressure of 1·25 atmospheres,

condensing at 30° (86° Fahr.), and cutting off at $\frac{2}{3}$ of the stroke.

Let L = the stroke of the piston be 2·28 metres = 7 feet 5·766 inches, we have

$E = \frac{2}{3}L = 1{\cdot}52$ mètres 4 ft. 5·176 inches; let $m = 2$.

$\pi = 950$ millimètres 37·406 inches, of mercury.

$P = \frac{2}{3}\pi$ 634 millimètres = 24·937 inches, of mercury.

$p = 31$ millimètres 1·220 inches.

and the available power is here $T_u = 225$ H.P.

The formula (2) gives $\frac{T^o_r}{T_u} = 0{\cdot}058$ or $T^o_r = 13$ H.P.

Thus an ordinary condenser offers a resistance, of which the work is equal to 0·058 of the useful work.

The formula (4) gives $\frac{T_r - T^o_r}{T^o_u} = 3{\cdot}07n$.

This coefficient 3·07 being considerable, it follows that if n is not a small fraction, the increase of work of resistance due to delay will be considerable. If for example we make $n = 1$, that is to say, if the condensation is in operation during the whole stroke of the piston, in its ascent or descent, the increase of work due to delay will be more than triple that which would exist were there no delay: in the particular case which we are considering, this increase would be equal to 53 H.P., or 0·24 of the available work.

It may thus be understood, of how much importance it is for the success of a surface condenser, to reduce the time during which the condensation takes place to a small fraction of that elapsing between two single strokes of the piston.

Section 2.

CAUSES OF DELAY OF THE CONDENSATION IN SURFACE CONDENSERS.

Let us then inquire into the causes of this delay of condensation, to see if we can destroy them or diminish their influence.

Evidently these causes are contained in the difficulty with which heat passes through the body which separates the condensing water and the steam, and are nothing else than the circumstances which accompany the phenomenon of the propagation of heat through this body.*

The rate of transmission of heat is expressed by the formula

$$V = S\,K\frac{a-b}{e} \qquad (1)$$

in which S is the area of each of the surfaces of the condenser, that passed over by the cold water, and that in contact with the steam; K the co-efficient of the conducting power of the body; e the thickness of the body; a and b the respective temperatures of the two surfaces.

But if one of these surfaces is covered with a crust of a thickness ε, of a substance which has K′ for its conducting power, the quantity V′ of heat which will pass in a unit of time will be

$$V' = S\,K\frac{a-b}{e+\frac{K}{K'}\varepsilon} \qquad (2)$$

(See Note 1.)

And we shall have the relation—

$$\frac{V'}{V} = \frac{1}{1+\frac{K}{K'}\frac{\varepsilon}{e}} \qquad (3)$$

Thus V′ is proportional to the conducting power K, and in the inverse ratio of the quantity $e+\frac{K}{K'}\varepsilon$, relative to the thickness of the metal and of the crust. But iron and copper

* Upon this subject, and as confirmatory of, as well as extending the views of the author, the highly important paper by Mr. Joule, published in the Philosophical Transactions for 1861, should be consulted.

Mr. Joule experimenting with *clean* metallic condensing surfaces, has shown that the great cause of the delay in surface condensation is due to the film of water from the condensed steam which obstinately adheres to the metallic surface by capillarity, in which there is no circulation to evect heat, and whose conductivity is extremely low.

are the only metals which we can employ practically and with advantage for surface condensers: let us proceed then on this hypothesis.

Thickness of the metal.—Water, and especially sea-water, having a corrosive action, very strong upon iron, and less strong, but nevertheless perceptible upon copper; these metals gradually become thin, whence arises the necessity of giving them a certain thickness, which should not be less than (5 millimètres) 0·197 inches for iron, and (2 millimètres) 0·079 inches for copper.

Conducting power of the metal.—These metals are good conductors, but several circumstances, inherent in the surface condenser, concur to destroy this fitness in them.

1st. The surface of the condenser in contact with the steam is always covered with a stratum or film of water, even when the surface is vertical, and, although in this case the film is very thin, it diminishes the conducting power considerably. The surface bathed by the condensing water is also covered with a thin film, which is changed with difficulty on account of the friction (its adherence), whatever be the velocity of the current of cold water. But we know from the experiments of MM. Thomas and Laurent, that the conducting power of copper represented by 19·11 is reduced to 1·22, when the film of liquid which wets its transmitting surface is not changed.

2nd. The surface in contact with the steam quickly becomes covered with a stratum of oxide; in the case of iron this crust adheres very firmly; always increases under the influence which produces it, and frequently attains a thickness of more than 1 millimètre = ·0394 inches. In the case of copper, the crust forms less quickly, and once formed, protects the metal from further action; but we may, without exaggeration, suppose it to be 0·1 millimètre = 0·0039 inches.

When the condensation is produced by sea-water, the other surface of the condenser remains clean, because the oxide

which forms there is dissolved by the sea-water. But, if it be supplied with fresh-water, this surface would be equally incrusted, and would assist in retarding the condensation still more. In this case the rate of transmission of the heat would be

$$V'' = SK.\frac{a-b}{1+\frac{K}{\gamma}\frac{}{e}+\frac{K}{K'}\frac{\varepsilon}{e}} \tag{4}$$

and we will have the relation—

$$\frac{V''}{V} = \frac{1}{1+\frac{K}{\gamma}\frac{\eta}{e}+\frac{K}{K'}\frac{\varepsilon}{e}} \tag{5}$$

Applying the formulæ (3 and 5) to surface condensers of iron or copper, and having the thicknesses above found necessary, we will have for iron $e=5$; $\varepsilon=1$; $K=374$; $K'=23$; $\eta=1$; $\gamma=23$; and we get

$$\frac{V'}{V}=0{\cdot}24 \text{ and } \frac{V''}{V}=0{\cdot}13;$$

That is to say, the rate of transmission is reduced by oxidation to 0·25 in the case of sea-water, and to 0·13 in the case of fresh water.

For copper we have—

$$e=2;\ K=898;\ K'=\gamma=23;\ \varepsilon=0{\cdot}1;\ \eta=1.$$

whence—

$$\frac{V'}{V}=0{\cdot}33 \text{ and } \frac{V''}{V}=0{\cdot}24.$$

3rd. The steam, in issuing from the cylinder, carries with it a small quantity of the tallow, with which the piston is lubricated. This fatty matter forms with the metallic oxide, and with the earthy particles which the steam brings from the boiler, an unctuous coating, of very bad conductivity, which soon acquires a considerable thickness, and which thus wholly obstructs condensation.

This coating of the condenser by the tallow, is a great

stumbling block for surface condensation; and of all the causes which unite in hindering the condensation this is the most active; and it may be affirmed that it will render powerless every apparatus of this sort from which its effects cannot be removed.

By the preceding analysis we see that to ensure the success of a surface condenser, it is necessary to make it of a metal which sea-water will not attack, which fresh-water and moist air will not oxidize, which is a good conductor of heat, and which is strong though thin; it is necessary to give it a large transmitting surface, without making the whole apparatus bulky; and, lastly, it is necessary to possess some means of destroying, from time to time, the coating of tallow which is produced on the transmitting surfaces.

Doubtless it is not impossible to satisfy every one of these conditions, but many of them appear to me difficult to overcome in the present state of our mechanical resources; so that I have thought proper to look elsewhere than in the principle of a monohydrous supply for the means of reaching the proposed goal.

CHAPTER VI.

PRINCIPLE OF MONOHYDROUS CONDENSATION.

THE means which we are about to examine can modify the difficulties which, as we have seen, render these inapplicable, and so avoid them. These difficulties arise from the employment of the surface condenser, and would cease, if we could make use of an ordinary condenser, where the steam and condensing water come into immediate contact. It is necessary then that the condensing water should be injected into the condenser, and it must be free from calcareous salts, and for this end one single and *unchanged volume of condensing water* must be used. At each stroke of the piston, a portion of this water must be introduced into the condenser, and the

hot water, extracted at the same stroke by the air-pump, must be carried into a cooler, where it will take a temperature sufficiently low to return it fit for condensation anew. The principle which we notice here, being characterized by the employment of one and the same quantity of water for condensation, I shall designate it for brevity sake *monohydrous* (direct) *condensation.*

The whole difficulty consists in cooling this water to a sufficiently low degree and in sufficient quantity for the wants of the condenser; and it will be generally necessary to employ for this end a great quantity of cold water, and coolers with greatly extended surfaces of a good conducting material.

But on the one hand, the water which is about to be recooled, in coming from the condenser will be charged with the grease which coats the transmitting surface. In the second place, the condensing water if obtained from a river or well, will contain some carbonate of lime, which will incrust the cooling surface more or less. The apparatus then must be of such an arrangement as to admit of cleaning these two surfaces from time to time.

Specification of the Apparatus.—Various means may be conceived for fulfilling the above conditions. The following, which can be applied either to fixed engines or those of steam-ships, appear to me to deserve the preference.

A pump (this may be the air-pump of the engine, or any other pump) lifts the water drawn from the condenser to a reservoir placed at the height of some yards, and above which is placed a cooler, consisting of vertical copper tubes, enclosed in a cylindrical case, also of copper.

The cold water descends from this reservoir into the tubes, which are plunged into cold water, continually renewed by a current directed from below upwards, and driven either by means of a fall of water, pumps, helices, &c.

To destroy the coating of the *interior* of these tubes, which

is produced by the grease, there is introduced into them, from time to time, an alkaline solution, concentrated and boiling, which dissolves the greasy matter.

The cleansing of the *exterior* of the tubes is performed by an analogous proceeding, by introducing into the place of the cooling water a weak solution of muriatic acid which dissolves the carbonate.

By means of a properly arranged system of cocks, these two operations are quickly executed, without trouble, without stopping the engine, and likewise without in the least interfering with its ordinary action. For this purpose the tubes, instead of being enclosed in one and the same case, are divided into several groups, each enclosed in a separate case, and are arranged so as to have one of these cases with its tubes supernumerary, so as to permit of change for any one, which can be set at rest while the others act, and can consequently be cleaned, as we are about to show, or may undergo any other repairs.

To make the above specification clearer, I shall here describe the apparatus as adapted for the engine of a steam ship.

Plate VI.—Fig. 5. Section of the ship through the engine-room.

Fig. 6. Horizontal section of the engines and coolers.

Fig. 7. Elevation of the cooler of one of the engines.

Fig. 8. Plan of the same cooler with section of one of the cases and one of the screws.

A^1, A^2, A^3, &c., are cylindrical copper cases, carrying at each extremity a tube plate, and terminated above and below by a hemispherical cap. They contain a great number of copper tubes soldered to the two plates. They are placed vertically along each side of the engine.

B, a reservoir receiving the cold water drawn from the condenser, and distributing it into the higher hemispherical caps, and thus into the tubes of the cases by means of the horizontal

pipe D, and the cocks f^1, f^2, f^3, &c. The water is cooled in its descent and runs into the lower hemispherical caps, and thence by the cocks and horizontal pipe E, conducts it by the branch C, into the condenser H; and this flow is regulated, according to the wants of the condenser, by a cock placed on this branch.

The ascending current of cooling water is here produced by the helices I^1, I^2, I^3, &c., moved by the engine shaft; the water is drawn from the sea by the lower pipes K, and thrown out by the upper pipes L; and as the screws and pipes are below the water-line X, the current is produced by a mere displacement of the water always at its natural level.

The draught of the helices operates by the branches N^1, N^2, N^3, &c., which communicate with all the cases at once. This communication can be cut off from each case by the puppet valves O^1, O^2, O^3, &c. Likewise the flow of water into the sea can be interrupted for each case by the puppet valves P^1, P^2, P^3, &c. The object of these upper and lower valves is to stop the action of any one of the cases without interfering with that of the others, when it is necessary to repair any one case or clean its tubes.

Cleaning of the interior of the Tubes.—Let us suppose this is to be done with the case A^1, for example: The case is shut off from the condenser and reservoir by turning the cocks e^1, f^1. The water actually contained in the tubes is expelled by opening the cock g^1, which admits the steam from the boiler by the pipe Q, and by opening the cock h^1, which brings back this water by the pipe R to the reservoir B.

When all this water is expelled (and this is known by the escape of steam from the extremity of the pipe which opens above the reservoir, B) the cocks J and g^1 are shut, then the cock l, placed above the second branch of the pipe R, is opened, which pipe communicates with a vessel containing the alkaline solution. Immediately this solution falls into the

interior of the tubes, and ascends so as to flow out by the small cock placed in the upper hemispherical cap. Generally, the contact of the cold solution, will suffice to dissolve the greasy matter which coats the tubes; but if it be necessary to employ this solution hot, the following process is adopted.

Before performing the previous manipulation, the cooling water is expelled from the case; for this purpose the valve a^1 is shut. The cock m^1 which admits the steam is opened, this discharges the cooling water into the sea by the pipe k^1. When the level of this water shall have descended to the bottom of the tubes (this will take place when steam issues from the cock n^1), the valve P^1 is shut. The steam is then let pass through the cock m^1 for some minutes, and during this time the alkaline solution is introduced into the tubes by the above-described manipulation. The solution will soon boil from contact with the steam.

After some minutes of contact with the alkaline solution the cleansing is complete. The solution is brought back into its receiver by reopening the cocks g^1, l; and when the steam is heard bubbling in this receiver it is a signal that all the solution has returned into it. Then the cocks l, h^1, g^1, m^1, n^1, are shut, and this part of the apparatus can be again made to act.

Cleaning of the exterior of the Tubes.—In sea-going steamers this operation is useless, because the sea-water slowly corrodes the copper, and keeps it continually clean. But where the cooler works with fresh-water, the tubes would be incrusted with carbonate of lime, and it is necessary to clean them as follows:—Use is made of the pipe S, whose vertical branch enters a receiver containing a weak solution of muriatic acid, and whose horizontal branch can conduct this solution into each of the cases by the cocks p^1, p^2, p^3, &c.

Taking again the case A^1, we begin by expelling the cooling water as has been said above; then, by opening the

cock p^1, the solution enters the case. Care must be taken to keep the cock g^1 open, to allow of the escape of the carbonic acid.

Then to bring back the solution into its receiver, the cock g^1 is shut, m^1 opened, and when the steam enters the receiver p^1 is shut, &c.

CHAPTER VII.

PRINCIPLE OF FEEDING WITH SUPERHEATED WATER.

We have proved, Chap. III., Sec. 2, that sulphate of lime is perfectly insoluble in either fresh or sea-water, at a temperature of 150° (302° Fahr.), and that the part of the carbonate of lime retained in solution after the expulsion of the carbonic acid in excess, alike completely precipitates at this temperature. This precipitate appears in the state of microscopic crystals, the greater part of which fall to the bottom of the vessel, the rest forming an incrustation on its sides.

If, then, before introducing the water into the boiler, it be exposed for some minutes to ebullition, at a pressure of 5 atmospheres (corresponding to 150° c. = 302° Fahr. of temperature) in a special vessel (which I shall call the *superheater*), and if this water be filtered, to separate it from the precipitate, it will be deprived of all its lime, and can no longer form incrustations.*

Let us observe, that the operation of filtration will be unnecessary in those instances where the following conditions are fulfilled:—1st. When the water can pass from the superheater into the generator as fast as the feed supplies it. 2nd. When the water continues almost at the same tem-

* This has since been, to some extent, carried into practice in the Hydratmo-purificateur of MM. Wagner and Schau, exhibited at the Great Exhibition of 1862—a description of which may be found in the *Practical Mechanics' Journal Record* of that Exhibition, page 236, and fully in *Le Genie Industriel*, No. 136, Tom. XXIII., for April, 1862.

perature in the generator as in the superheater; this will be the case in those boilers which work unintermittingly (as in steamships) and at a pressure of from 4 to 5 atmospheres. In the latter case, in fact, the water not being able to redissolve the precipitate, may remain in contact with it, without being able to form incrustations.

Thus we come to the conclusion that to apply this principle to navigation, with all possible simplicity, it will be necessary to employ engines working at a high pressure, say from 4 to 5 atmospheres. This conclusion is the more acceptable as it concurs in increasing the available power of the steam, by increasing the amount of cut-off.

But for boilers which have an intermittent action with long stoppages (as in almost all fixed engines which only work 12 or 15 hours of the 24), filtration will be necessary. It will be equally so for engines which act at a low or medium pressure, and likewise for locomotives, because they cannot draw their supply of water directly from the superheater. In these different instances the water is reduced before entering the boiler, or afterwards, to a temperature allowing of the re-solution of the calcareous precipitate. Nevertheless, filtration is not absolutely necessary, except for locomotives; we shall see hereafter how we may deal with high and medium pressure fixed engines, and with an intermittent action.

During the superheating of the water, whatever be its nature, it will disengage air and carbonic acid, for which a means of escape must be provided. Some steam which should be made use of will escape at the same time with them. For this purpose the superheater should carry a valve loaded with a weight which permits it to rise at a pressure of from 5 to 5·5 atmospheres, and this valve opens into a pipe conducting the gases and steam into the steam-chests of the two generators.

The water which should be raised to 150° (302° Fahr.) in

the superheater, acquires there 140° (284° Fahr.), assuming it to have 10° (50° Fahr.) of initial temperature; the generator will then only have to transmit to it $640-140=500$ units of heat. From whence results a necessary relation between the heating surfaces of the superheater and boiler. This relation will be $\frac{140}{500}=0{\cdot}28$; a figure which must be taken as the *minimum;* for the superheater will be subject to incrustation, although the generator be freed from it.

It is obvious that the effects of a supply of superheated water do not absolutely prevent incrustation, since it exists even in the superheater, whose heating surface is to the total heating surface as 0·28 is to 1·28, or as 22 in 100. But in profiting by the experience we have gained from the boiler invented by M. Spiller, and subsequently from that of M. Arnier, we can construct the superheater so as greatly to reduce the effects of incrustation. This depends on the fact, that if in a boiler we arrange tubes of small diameter above the fire, communicating at one end with the water at the bottom of the boiler, and at the other with that at the top; such tubes will not be at all incrusted but will remain perfectly clean.*

Superheating Apparatus.—From what precedes I am led to propose the following apparatus for the superheater, which I shall describe as applied to the boiler of a steamship, but which is equally suitable for all kinds of engines, fixed or

* This fact is explained by the properties which we have recognized in sulphate of lime: a rapid current of water is established in these tubes, which submitted thus in small quantity to the action of the fire, almost instantly acquires a high temperature which precipitates the calcareous salts in the state of sulphate, and the friction caused by the water, and especially by the crystalline and angular precipitate which is dragged with it, cleans the surfaces, and incessantly detaches from them the particles which tend to fix themselves there.

locomotive. 1st. *Superheater for Steam-ships.*—(Plate VI., Figs. 9, 10.) A is a boiler-plate cylinder, terminated by two plane surfaces, covering the whole apparatus, and containing the water which is to be heated. B is another cylinder riveted to the two plane surfaces of the cylinder A, and joining in front with a case C, of flat sides, which forms the envelope of the fire and ash-pit. This cylinder B conducts the smoke to the back, whence it passes into the two pipes D, D′, which brings it back to the front; it then returns to the back by two other pipes E, E′, which bring it into the funnel F. This cylinder B, and the pipes D, D′, E, E′, being riveted to the two surfaces of the cylinder A, strengthen them against internal pressure, and are easily cleaned.

In the cylinder B are tubes *a* of copper, fixed at one end to a case *b*, resting by brackets *c*, on two sliders or supports *d*, fixed on the fire-grate. The other end of these tubes is fixed to another case, riveted to the back end of the cylinder A. This case is divided into two equal compartments *g*, *h*, of which the lower one communicates with the bottom of the boiler by the pipe *f*, and the upper communicates with the top of the boiler by traversing the cylinder B.

These tubes, *a*, receiving the radiation of the fire and the contact of the flame, rapidly transmit a great quantity of heat to the water they contain, and which at once becoming less dense, tends to rise. A continuous current of water is established, beginning at the bottom of the pipe *f*, and passing through the compartment *g*, the tubes which open into this compartment, then through the case *b*, the tubes which open into the compartment, *h*, and thence entering the boiler A, where it strikes against the sides of the cylinder B.

By this movement the water is rapidly brought into fresh contact with these heating surfaces, and quickly brought to the desired temperature of 150° (302° Fahr.) After having

remained some time in the heater, the water enters the generators by passing through the pipe K, the extremity of which is not plunged more than an inch below the surface. And the cold water is supplied to the heater by the pipe *i*, by means of a feed-pump.

The calcareous precipitate, which consists of pretty heavy crystals of sulphate and carbonate, is brought into the tubes, because the motion of the water is rapid there, but on emptying at the top of the boiler, over *h*, they fall down almost vertically, and accumulate at the bottom; so that the pipe K, placed at the other end, and at the top, only draws in small quantities of this precipitate; besides, as we have before said, this small quantity of precipitate cannot dissolve again if the boiler work at between 4 and 5 atmospheres.

G is a dome to receive the gases disengaged from the water, until these be sufficiently strong to raise the valve J, which allows them to escape by the pipes *m*, *n*, into the steam chests of the generating boilers.

It is seen that the superheater which I propose, presents the general arrangement which characterizes the boilers of Spiller and of Arnier. This arrangement is the most favourable for the rapid production of steam, and can, therefore, be recommended for adoption in the boilers of steamers and fixed engines.

Supposing then that we adopt this kind of boiler for a steamship; the evaporating system should be composed of two equal boilers, of the same type as the superheater above described, and of a third similar heating vessel, performing the part of superheater. This third heating vessel should possess at least 0·22 of the total heating surface. This condition would admit of its having less dimensions than the boilers. But it is better to make the three boilers equal, because the superheater having then a heating surface greater by a third than what is necessary, the fire may be much less

intense there, and consequently the incrustation of the fire-grate, and other parts of its interior, will have but a small influence over the utilization of the fuel, and will not create any appreciable danger of explosion.

2nd. *Superheater for fixed Engines.*—The apparatus which I have just described only wants one addition to become applicable to engines whose action is not continuous, or which work at low or medium pressure; the object of such addition being to filter the water coming from the heater, before it enters the generator.

The filter invented by M. Fonvielle provides the means of performing this.

Fig. 11, Plate VI., gives a section of the filtering apparatus. H is a boiler-plate cylinder, terminated by two spherical caps, one of which L, forming the cover, is riveted, and carries a pipe and cock *o*, for the escape of the filtered water. The other cap has also a pipe and cock *p* to expel, from time to time, the mud accumulated under the filter. M, is a cylinder, open at both ends, of a somewhat smaller diameter to the cylinder H, and resting on a ring fixed to the cylinder H, and forming a staunch joint with this ring by the interposition of an hempen packing. This cylinder carries the filtering material, consisting of a stratum of sand *s*, and a stratum *r*, formed of shreds of sponge. These two strata are held and fixed, between three plates, pierced with a great number of small pin-holes, which bind the whole system of the filter to the lower cap. This arrangement admits of easily taking asunder the filter for repairs or cleaning.

The pipe *u* communicates with the water of the superheater at an inch or two below its surface, and brings this water beneath the filter by the cock *v*. The cock *x*, which brings this water above the filter, has for its object, to clean the filter by the process shown by M. de Fonvielle, viz.: by directing the current of water above and below the filter by

an alternate and rapid jet from the cocks v and x, thus producing shocks which open the pores of the filter.

There are for each superheater at least two filters, in use alternately, and they are placed sometimes on the heater, and sometimes in another place more convenient for cleaning and repairs. The filtering surface will be proportioned to the quantity of water to be passed through it. We know on this point, from the report made to the Acadèmie des Sciences by M. Arago, on the filter of Fonvielle, that one square mètre = 10·763 square feet of filtering surface, under a difference of pressure of 1·6 atmospheres furnishes more than two cubic mètres = 35·315 cubic feet of water per hour.

Here the quantity of water passed through will be much more considerable, for the difference of pressure will be much greater, and the impurities of the water less clogging, because they will be made coherent and collected by the boiling.

The employment of the filter would be the most certain means of avoiding incrustation in fixed engines of an intermittent action, and it is indispensable for those engines which act at a low pressure. But we may absolutely neglect them in fixed high-pressure engines, and even those of a medium pressure.

In fact the sulphate of lime, when just precipitated at a high temperature, is anhydrous, perhaps completely, certainly in great part, and in this state it redissolves with difficulty, even in ordinary temperatures, and, *a fortiori*, at a temperature of from 120° to 130° (248° to 317° Fahr.) If then it be arranged that from the evening until the following morning, the temperature of the boiler shall not fall more than ten degrees (from 248° to 317° Fahr., in the case of a medium pressure boiler), the water within it will not redissolve the precipitate sensibly. Now the cooling of the boiler can easily be kept within these limits, or nearly so, by intercepting all draught of air in the flues.

A more certain method of avoiding all inconvenience which might result from the re-solution of the precipitate, consists in emptying every morning the water in the boiler, and making it pass again into the superheater. For this purpose we commence by lighting the fire under the super-heater only; when the water there attains 130° (317° Fahr.), the cock which brings this water to the upper part of the boiler is opened, and with it another cock placed on a pipe which joins the bottom of the boiler with a receiver. It is evident that the water which has passed the night in the boiler, being colder, will escape into this receiver, and will be replaced by water coming at the same instant from the heater.

3rd. *Superheater for Locomotives.*—On railways the feeding-water is supplied from tanks placed at different points along the line, and received into the tender, whence the feed-pump draws it during the journey, to inject it into the boiler of the locomotive. Generally the water is raised into these reservoirs by a steam-engine, established *ad hoc.*

To this already-existing plant, there must be added, at each of these points of the line, a superheater with a filter, such as we have just described, and also a refrigerator designed to communicate to the cold water, which supplies the superheater, the excess of heat which the water coming from the filter possesses, so as not to waste any heat. Here may be applied with advantage the refrigerator which I described farther back in connexion with the process of monohydrous condensation. By this means the filtered water can be made to enter the reservoir at a temperature which will be almost the mean between 150° and 10°, say 85° (302° and 50°, say 185° Fahr.)

The loss of heat due to its stay in the reservoir will be slight, if care be taken to place this reservoir over the furnace of the superheater, or of the steam-engine for pumping. Thus the tender will receive the water at about 80° (176°

Fahr.), and it will be easy to make the tank of the tender, so that it shall only permit a small quantity of heat to escape, say 10° (50° Fahr.) at most. Hopes may be entertained then, that the water will arrive in the locomotive at a temperature of at least 70° (158° Fahr., and having only experienced a loss which will not exceed 15°, or $\frac{15}{640}$ or $\frac{1}{42}$ of the heat employed to free it of its impurities.

CHAPTER VIII.

CONDENSING engines may employ either of the two means which we have described, and founded on two different principles, *i. e.*, *monohydrous condensation*, and the *feeding with superheated water;* it may be useful to inquire which of these means is to be preferred.

The monohydrous condensation has the great advantage of supplying the condenser with water freed from all gas. Ordinary water contains about twenty times its volume of air, and this gas, disengaging itself, in great part in the condenser, tends to diminish the vacuum there. The air-pump must then be of large dimensions, (in general its diameter is one-fourth or one-fifth that of the cylinder). The monohydrous condensation would permit of considerably reducing these dimensions, and consequently diminishing the useless work of the engine.

But various drawbacks are found united to this advantage.

1st. The refrigerator, designed to cool the condensing water, is a cumbrous apparatus. This fault, perceptible enough in a steam-ship of large tonnage, would be decisive for small boats, and would render the system of monohydrous condensation inapplicable to them.

2nd. In the working of the engine, the boilers, and the refrigerator, some water is lost, sometimes in the liquid state,

by leakage at the joints of the boiler-plates, sometimes in the state of steam, by the valves, the stuffing-boxes, &c.

3rd. The refrigeration of the condensing water requires the employment of a considerable quantity of cooling water. In the case of a steam ship, this water is on a level with the foundation of the engine, and it can be so arranged as not to have to lift it, but only communicate to it a horizontal displacement. It will not be the same in general for land engines; the cooling water here must often be taken from a well, and often from depths great enough to demand a perceptible quantity of work.

4th. Although it is true that on board steam-ships indefinite supplies of water may be had, this has not always a sufficiently low temperature to act as cooling water. Thus there are certain parts of the ocean where the surface of the sea has temperatures of 20°, 25°, and 30° (68°, 77°, and 86° Fahr.), and even higher.

As regards river navigation we may remark that at certain times of the year the currents of water take temperatures of from 20° to 25° (68° to 77° Fahr.) Under these circumstances the condensing water could not be sufficiently cooled to produce a good condensation.

The feeding with superheated water requires more simple apparatus (the more so since filtration is not necessary), and all the parts of which concur with the evaporation, for the work of the superheater diminishes that of the boilers.

It is true that the superheater is subject to incrustation, but this only on the less heated part of the heating surface; and since the fire may be less intense there than in the furnaces of the boilers, the incrustation will not produce any appreciable chance of danger, and will only involve a small loss of heat. Thus, although this system does not permit of any reduction in the work of the air-pump, I think no one will hesitate to give it the preference for ocean or river navigation.

For land engines, on the contrary, when well-water is procured from a small depth, the system of monohydrous condensation offers greater advantages.

CONCLUSIONS.

THE conclusions to be drawn from this Memoir may be summed up in the following :—

1st. Steam navigation and industry are interested in the highest degree in the question of preserving boilers from incrustation.

The simple *suppression of incrustation* alone, will economize, on an average, about 40 per cent. of the actual consumption of fuel.

The absence of incrustation, will permit of *substituting engines of a medium or high pressure*, for those condensing on Watt's system, for ocean navigation, and of economizing 50 per cent. of fuel by this means. It follows that the whole realized saving in marine engines will be about 66 per cent.

Other important consequences will follow from the absence of incrustation:—increase of the durability of the boilers; considerable addition to the available tonnage of steamers; security from explosion.

2nd. In boilers fed with fresh water, incrustation is produced by carbonate and sulphate of lime.

In boilers which evaporate sea-water, incrustation is produced by sulphate of lime only.

The solubility of the sulphate of lime in salt-waters has led to a process for diminishing the incrustation due to sea-water, namely, the process of evacuation. But it is only applicable to low-pressure boilers; and again, it only protects the "indirect" heating surface.

3rd. To prevent incrustation in medium or low-pressure

boilers, there is no other resource but feeding with water deprived of calcareous salts in solution. Three means present themselves of realizing this idea, viz.:—

1. The employment of a surface condenser to collect in the pure state the water produced by the condensation of the steam on its exit from the cylinder. This is *monohydrous feeding*. This means appears inapplicable—in so far as it diminishes considerably the useful effect of the engine—in consequence of the delay which the condensation experiences in surface condensers.

2. *Monohydrous Condensation.*—The employment of one and the same volume of water, previously deprived of calcareous salts, to produce condensation in the condensers now in use.

This means may be applied with advantage to fixed engines, in localities where cold water may be had, as from wells of small depth.

3. *Feeding with superheated Water.*—Previous purification of the feeding-water, by the precipitation of the salts of lime, produced by means of boiling, under a pressure of from 5 to 6 atmospheres.

This means will be most of all advantageously employed in steam-ships working at a high pressure. It is suitable also for boats acting at a medium pressure, and for fixed medium or high-pressure engines in localities badly supplied with cold water. For these applications the process will not require any other apparatus than the superheater, whose work will lessen that of the boilers.

The process of feeding with superheated water is the only one applicable to locomotives in the present state of railway plant. For this application it is necessary to add to the superheater a filtering apparatus, designed to separate the water from the precipitate of calcareous salts.

NOTES.

I have thought it desirable, in the course of this Memoir, to limit myself to the enunciation of results, without going through the scientific investigations which have conducted me to them, and to reserve a special place for these details, so that the reader may examine or omit them at pleasure.

NOTE No. 1.

CALCULATION OF THE LOSS OF HEAT DUE TO INCRUSTATION.

1. Let us assume two boilers, o, o', equal and placed under the same conditions, except in this respect—that one, o', is lined with a calcareous crust of a uniform thickness over the whole heating surface of the interior; the other, o, having no calcareous crust.

I suppose that they are managed so as to give the same quantity of steam in the same time.

On this hypothesis we proceed in reality, for in the factory, the work of the engine is fixed, and the boiler must furnish the quantity requisite for this work, and if, in consequence of incrustation, it is less capable of evaporation, the want is supplied by increasing the intensity of the fire. There must result from this expedient a greater loss of heat by the draught of the chimney, and by the external radiation of the furnace. It is this increased loss which I am about to estimate.

In the absence of precise facts, I shall assume such as approach the real state of the case as nearly as possible, but all tending to diminish the result; so that this result also may be as approximate an estimate as possible, but yet below the actual loss. The increase of the loss of heat due to the exterior radiation of the furnace being inconsiderable, I shall neglect it, and engage in the consideration of the increased loss due to the draught.

2. Let P represent the loss of heat by draught for the boiler o, and P′ the loss for the boiler o'. The ratio $\frac{P'}{P}$ will be equal to the ratio of the quantities of gas passing in a given time into the chimney, multiplied by the ratio of the mean temperatures T and T′ of these same gases. That is to say, by denoting the respective weights of these same quantities of gas by π and π', there will be

$$\frac{P'}{P} = \frac{\pi'}{\pi} \cdot \frac{T'}{T}$$

Disregarding π and π' I shall suppose them equal for the moment, only taking

their difference into account, at least approximately, afterwards. This hypothesis leads to too small a value for $\frac{P'}{P}$, for it is evident that π', relatively to the incrusted boiler, which consumes more fuel than the not incrusted one, is greater than π. Let $\frac{\Pi_o}{P}$ be this too small value and put $\frac{\Pi_o}{P} = \frac{T'}{T}$ and consequently

$$\frac{P'}{P} = \frac{\Pi_o}{P}\frac{\pi'}{\pi}$$

3. Let A be the mean temperature of all the points of the exterior heating surface of the boiler o, and A′ the analogous quantity for the boiler o'.

These quantities, A, A′, the temperatures of the heated bodies, evidently depend on the quantities T, T′, the temperatures of the heating bodies, and we may put

$$\frac{T}{T'} = m\frac{A}{A'} \text{ or } \frac{\Pi_o}{P} = \frac{m'}{m}\frac{A'}{A}.$$

These co-efficients m m' are unknown, and depend on various circumstances (such as the radiation of the grate; the exterior radiation of the furnace; the arrangement of the flues; the velocity of the gas through these; the rate of transmission of the heat through the metal, &c., &c.), which circumstances are either equal in both boilers, or variable by the sole effect of more or less thick incrustation; so that all these circumstances would be the same for both boilers if there were no incrustation, and we would have $m = m'$. By designating the variable thickness of the crust uniformly spread over the surface by ϵ, we may consider $\frac{m'}{m}$ as a function of ϵ and put $\frac{m'}{m} = f(\epsilon)$, an unknown function, of which it is only known that $f(o)=1$. We will put then

$$\frac{\Pi_o}{P} = f(\epsilon)\frac{A'}{A}. \tag{1}$$

4. Let us endeavour to determine the ratio $\frac{A'}{A}$ by the consideration of the movement of the heat through the plates of the boilers.

Since we shall want a co-efficient of the conductibility of the metal, which co-efficient, as physical laws give it, has relation to metal with a well-cleaned surface; and since in practice the surfaces of boilers are never clean, but covered over in the interior with a crust of oxide, generally of small thickness, but nevertheless exercising a certain influence over the conductibility; we shall take into consideration a third, ideal boiler, Ω, equal to either of the others, and subject to the same conditions, but perfectly clean; whilst o and o' are supposed covered with a crust of oxide of the thickness η; and besides o' will have a further calcareous crust of a thickness ϵ superposed on this crust of oxide.

Let any points whatsoever, M, M′, μ, be taken respectively on the exterior surface of the three boilers (Fig. 12, Pl. VI.) Let α, α', θ, be the temperature of the indefinitely small element of the heating-surface respectively in each of these points.

Q, Q′, χ, The quantity of heat which passes in a unit of time through the whole heating-surface S in each of the boilers respectively.

i, The temperature of the interior surface at the point M_1 of the boiler o, at the contact of the metal with the crust of oxide.

i', The temperature at the point M″ of the boiler o', at the contact of the metal with the crust of oxide.

i'', The temperature of the crust of oxide at the point $M''_{,,}$ of contact of the oxide with the calcareous crust.

b, The temperature of the water in each of the three boilers.

K, The co-efficient of the conductibility of the metal.

K′, The co-efficient of conductibility of the calcareous crust.

γ, That of the stratum of oxide.

e, The thickness of the metal in the three boilers.

ϵ, The thickness of the calcareous stratum.

η, The thickness of the stratum of oxide.

ds, The differential element of the heating-surface S of each boiler.

There will be for the boilers Ω and o the differential equations,

$$d\chi = K\frac{\theta - b}{e}ds,\ dQ = K\frac{a-i}{e}ds.$$

θ, a, i, vary with the point of the surface considered, and may be regarded as functions of the element s of the surface, taken for an independent variable, and reckoned, from a single origin, at one extremity of the surface, such, that the whole heating-surface shall be comprised in $s=o$ and $s=S$. We may then integrate these differential equations between the limits $s=o$ and $s=S$ and have

$$\chi = \frac{K}{e}\left[\int_o^s \theta ds - bS\right],$$

$$Q = \frac{K}{e}\left[\int_o^s a ds - \int_o^s i ds\right].$$

or,

$$\left.\begin{aligned} \frac{\chi}{S} &= \frac{K}{e}\left[\frac{\int_o^s \theta ds}{S} - b\right], \\ \frac{Q}{S} &= \frac{K}{e}\left[\frac{\int_o^s a ds}{S} - \frac{\int_o^s i ds}{S}\right] \end{aligned}\right\}. \qquad (2)$$

The expressions $\frac{\int_o^s \theta ds}{S}$; $\frac{\int_o^s a ds}{S}$; $\frac{\int_o^s i ds}{S}$; are respectively the mean temperatures of all the elements of the exterior surface in the boilers Ω and o, and of the interior surface of the boiler o at the contact of the metal and oxide. Designating by ΘAI these means of temperature, the equations (2) become:—

$$\frac{X}{S} = \frac{K}{e}(\Theta - b);\quad \frac{Q}{S} = \frac{K}{e}(A - I). \qquad (3)$$

When the dynamical equilibrium of heat is established in the boiler o, the quantity $\frac{Q}{S}$ which traverses the unit of surface of the metal, is equal to the quantity which traverses the crust of oxide on the unit of surface, which quantity is evidently expressed by $\frac{\gamma}{\eta}(I-b)$. We then have the equation

$$\frac{K}{e}(A-I)=\frac{\gamma}{\eta}(I-b);$$

whence we derive

$$I=\frac{KA\eta+\gamma be}{\gamma e+K\eta}$$

Substituting this value of I in the second of the equations (3) we have

$$\frac{Q}{S}=\frac{K\eta}{\gamma e+K\eta}(A-b),$$

and dividing this by the first equation (3) we have

$$\frac{Q}{\chi}=\frac{A-b}{\Theta-b}\;\frac{1}{1+\frac{K\eta}{\gamma e}}. \tag{4}$$

For the boiler o' we have an equation analogous to the second of the equations (3) and which will be :—

$$\frac{Q'}{S}=\frac{K}{e}(A'-I'),$$

to which must be joined the two following equations, which express the state of dynamical equilibrium of the heat, in the metal, the coat of oxide, and the calcareous crust.

$$\frac{K}{e}\;(A'-I')=\frac{\gamma}{\eta}\;(I'-I'')$$

$$\frac{\gamma}{\eta}\;(I'-I'')=\frac{K}{\epsilon}\;(I''-b),$$

A', I', I'', having significations analogous to the quantities A and I, and relating to the points $M', M'', M'_{,,}$ of the boiler o'. From these equations there is derived a value for I' independent of I'', and by substituting it in the preceding equation we have

$$\frac{Q'}{S}=(A'-b)\frac{K\gamma K'}{K'\gamma e+KK'\eta+K\gamma\epsilon}$$

and dividing this equation, member by member, by the first of the equations (3) there comes

$$\frac{Q'}{\chi}=\frac{A'-b}{\Theta-b}\;\frac{1}{1+\frac{K}{\gamma}\frac{\eta}{e}+\frac{K}{K'}\frac{\epsilon}{e}}. \tag{5}$$

And dividing this equation, member by member, by the equation (4) we have :

$$\frac{Q'}{Q}=\frac{A'-b}{A-b}\;\frac{1+\frac{K}{\gamma}\frac{\eta}{e}}{1+\frac{K}{\gamma}\frac{\eta}{e}+\frac{K}{K'}\frac{\epsilon}{e}}. \tag{6}$$

Such is the general relation which exists between the quantities of heat, which, in a unit of time, traverse the heating surfaces of the two equal boilers, both covered with a coat of oxide, and placed under the same circumstances, except that one is incrusted, and the other not incrusted.

5. It is now necessary to introduce into this equation (6) the hypothesis of No. 1, expressing that the quantities of steam produced in the same time by the two boilers are equal; we must then make $Q'=Q$, and we have

$$1=\frac{A'-b}{A-b}\;\frac{1+\frac{K}{\gamma}\frac{\eta}{e}}{1+\frac{K}{\gamma}\frac{\eta}{e}+\frac{K}{K'}\frac{\epsilon}{e}}$$

whence we derive

$$\frac{A'}{A}=1+\frac{\frac{K}{K'}\frac{1}{e}\left(1-\frac{b}{A}\right)}{1+\frac{K}{\gamma}\frac{\eta}{e}}\epsilon,$$

and again,

$$\frac{A'}{A}=1+M\epsilon,$$

by putting

$$M=\frac{\frac{K}{K'}\frac{1}{e}\left(1-\frac{b}{A}\right)}{1+\frac{K}{\gamma}\frac{\eta}{e}}$$

substituting this value of $\frac{A'}{A}$ in equation (1), we have

$$\frac{\Pi_0}{P}=(f\epsilon)\,[1+M\epsilon]. \tag{7}$$

6. The equation (7) is of the form $y=[1+Mx]\,f(x)$. If this is geometrically represented by a curve B A (Fig. 13, Plate VI.), it will pass into a point B of the axis of y, at a height $OB=1$. For $x=o$ we have

$$y_0=f(o)=1.$$

Let us examine some of the properties of this curve, deduced from the very nature of the question.

In the first place, for positive values of x this curve will always remain above the line B X′ parallel to the axis of x because

$$\frac{\Pi_0}{P}=\frac{T'}{T}>1$$

It is also necessary, from the nature of the question, that this curve have no contrary flexure, and that it always rise from the point B, for the ratio $\frac{\Pi_0}{P}$ will always increase with the thickness of the crust, and it is, nevertheless, possible that at a certain thickness of the crust, the ratio $\frac{\Pi_0}{P}$ shall not increase further;

that is to say, that the curve B A shall take a direction parallel to the axis of x, having passed a certain value of x.

Then the differential co-efficient of this curve is always positive.

This co-efficient is

$$\frac{dy}{dx}=\mathrm{M}f(x)+(\mathrm{M}x+1)f'(x)\,;$$

and since $f(x)$ is positive, M is also always positive, since $\frac{b}{\mathrm{A}}$ is always less than unity, so also $f'(x)$ must be always positive.

But the co-efficient for $x=o$ becomes

$$\frac{dy_o}{dx}=\mathrm{M}f(o)+f'(o)=\mathrm{M}+f'(o).$$

If we neglect the term $f'(o)$ which is positive, and consequently if we make $\frac{dy_o}{dx}=\mathrm{M}$ we will have a curve, B C, which at the point B will be more inclined towards B x' than the curve B A, and whose co-ordinates will have less values than those of $\frac{\Pi_o}{\mathrm{P}}$.

Nevertheless, let us take this curve, B C, instead of B A, and thus we shall have for $\frac{\Pi_o}{\mathrm{P}}$ less than the actual values.

7. This curve B C, of which we only know the point B, and the direction at this point, cannot be determined. But, considering that it is continuous, and without contrary flexures, and that it cannot at most deflect sufficiently to become parallel to the axis from x, we may substitute for it a parabola, which shall be tangent to it at the point B, and whose axis shall coincide with the axis of x. It is certain that in the neighbourhood of the point B, the ordinates of this parabola, will be equal to those of the curve B C, and that they differ little from them, more or less, at points not far from the point B.

This parabola, represented by B D, will be of the form $y^2=px+q$; and to determine the co-efficients we have

$$y_0^2=1=q;\ \frac{dy_o}{dx}=\frac{p}{2y_o}=\mathrm{M} \text{ or } p=2\mathrm{M},$$

that which gives the parabola

$$y^2=2\mathrm{M}x+1 \text{ or } y=\sqrt{1+2\mathrm{M}x}.$$

Thus we shall take for $\frac{\Pi_o}{\mathrm{P}}$ instead of the exact values represented by the ordinates of the curve B A, the following expression, which, for points but little removed from B, or for small thicknesses of crusts, will give smaller values.

$$\frac{\Pi_o}{\mathrm{P}}=\sqrt{1+2\mathrm{M}\epsilon}. \tag{8}$$

We must fix the value of the constant A which enters into the co-efficient M.

A, expresses the mean temperature of the exterior heating surface of the not incrusted boiler. Since we cannot *exactly* find this quantity, I shall give to

it a value such that there shall result from it values for $\frac{\Pi_o}{P}$, again inferior to the exact values. But M is still smaller as A is smaller. We shall then diminish the values of $\frac{\Pi_o}{P}$ if we give to A less than its true value.

Let us observe, that when the furnace is in a medium condition of draught (and we shall suppose that this is the case at present), the gases of the combustion enter the chimney at a mean temperature of about 300° (572° Fahr.) But the mean temperature of the exterior heating surface is superior to that of the gases; for this surface receives, besides the contact of these gases, the radiation of the furnace and that of the flues. Then by supposing A=300°, we make a supposition which diminishes the values of $\frac{\Pi_o}{P}$. We shall thus have

$$M=\frac{\frac{K}{K'}\frac{1}{e}\,1=\left(1-\frac{b}{300}\right)}{1+\frac{K}{\gamma}\frac{\eta}{e}}.$$

The quantity b, and consequently M, varies with the pressure, and we shall find it according to each case, viz.:—

For low pressure (1·25 atmosphere),

$$b=105^\circ\ (221^\circ \text{ Fahr.}) \text{ and } M=0{\cdot}65\frac{\frac{K}{K'}\frac{1}{e}}{1+\frac{K}{\gamma}\frac{\eta}{e}};$$

For medium pressure (3 atmospheres),

$$b=135^\circ\ (295^\circ \text{ Fahr.}), \text{ and } M=0{\cdot}55\frac{\frac{K}{K'}\frac{1}{e}}{1+\frac{K}{\gamma}\frac{\eta}{e}};$$

For high pressure (5 atmospheres),

$$b=153^\circ\ (307^\circ{\cdot}4 \text{ Fahr.}), \text{ and } M=0{\cdot}49\frac{\frac{K}{K'}\frac{1}{e}}{1+\frac{K}{\gamma}\frac{\eta}{e}};$$

and the expression (8) becomes

Low pressure

$$\frac{\Pi_o}{P}=\sqrt{1+1{,}3\frac{\frac{K}{K'}\frac{1}{e}}{1+\frac{K}{\gamma}\frac{\eta}{e}}\,e}. \tag{9}$$

Medium pressure

$$\frac{\Pi_o}{P}=\sqrt{1+1{,}1\frac{\frac{K}{K'}\frac{1}{e}}{1+\frac{K}{\gamma}\frac{\eta}{e}}\,e}. \tag{10}$$

High pressure

$$\frac{\Pi_o}{P}=\sqrt{1+0{,}98\frac{\frac{K}{K'}\frac{1}{e}}{1+\frac{K}{\gamma}\frac{\eta}{e}}\epsilon}. \tag{11}$$

10. We must, however, from $\frac{\Pi_o}{P}$ pass into $\frac{P'}{P}$ or at least into an expression which gives values more approximate to the reality, than those of expression (8); and also take into account the difference of weights π and π' of the gases of the combustion.

For the same fuel the weight of the gases of combustion is proportionate to the quantity of fuel burned. Let U and U′ be the quantities of fuel burned in a unit of time for the two boilers o and o', we shall have $\frac{\pi'}{\pi}=\frac{U'}{U}$, and replacing $\frac{\pi'}{\pi}$ by this value in the expression of $\frac{P'}{P}$ we shall have

$$\frac{P'}{P}=\frac{\Pi_o}{P}\frac{U'}{U}. \tag{12}$$

Supposing that the external radiation of the furnace be the same for both boilers, which is practically exact, we shall have

$$U'=U+P'-P \text{ or } \frac{U'}{U}=1+\frac{P'}{U}-\frac{P}{U}. \tag{13}$$

If in the place of this value of $\frac{U'}{U}$ we take this $\frac{u_o}{U}=1+\frac{\Pi_o}{U}-\frac{P}{U}$ in which $\frac{P'}{U}$ is replaced $\frac{\Pi_o}{U}$ which is less than the former, we shall have too small a value, and, consequently, the new expression resulting from it, for $\frac{P'}{P}$ will be too small; let us designate it by $\frac{\Pi_1}{P}$ we shall have

$$\frac{\Pi_1}{P}=\frac{\Pi_o}{P}\left[1+\frac{\Pi_o}{U}-\frac{P}{U}\right]$$

an expression to which must be joined this

$$\frac{\Pi_o}{P}=\sqrt{1+2\,M\epsilon}$$

whence we deduce

$$\frac{\Pi_o}{U}=\frac{P}{U}\sqrt{1+2\,M\epsilon}.$$

The ratio $\frac{\Pi_1}{P}$ thus obtained will be nearer $\frac{P'}{P}$ than $\frac{\Pi_o}{P}$ is.

Observe also that $\frac{\Pi_1}{U}$ is nearer $\frac{P}{U}$ than $\frac{\Pi_o}{U}$ is. If then in the expression (13) we replace $\frac{P'}{U}$ by $\frac{\Pi_1}{U}$ we shall have another ratio which we shall designate by $\frac{u_1}{U}$

always inferior to $\frac{U'}{U}$ but approximating nearer than $\frac{u_0}{U}$ and by taking this ratio in place of $\frac{U'}{U}$ in the expression (12), we shall have a new value, which we shall designate by $\frac{\Pi_2}{P}$ nearer $\frac{P'}{P}$ than $\frac{\Pi_1}{P}$ is; we thus have

$$\frac{\Pi_2}{P}=\frac{\Pi_0}{P}\left[1+\frac{\Pi_1}{U}-\frac{P}{U}\right]$$

an expression to which this, whose value we can get, must be joined:

$$\frac{\Pi_1}{P}=\frac{\Pi_0}{P}\left[1+\frac{\Pi_0}{U}-\frac{P}{U}\right]$$

whence

$$\frac{\Pi_1}{U}=\frac{P}{U}-\frac{\Pi_0}{P}\left[1+\frac{\Pi_0}{P}-\frac{P}{U}\right]$$

By continuing this method of approximation, deducing each one from the preceding, we obtain successive expressions, giving values more and more approximate to $\frac{P'}{P}$, regard had to the weights of the gases of combustion, but always inferior to the true value, on account of the hypothesis made as to the curve B C, and the value of A. These expressions have for a general formula

$$\frac{\Pi_n}{P}=\frac{\Pi_0}{P}\left[1+\frac{\Pi_{n-1}}{U}-\frac{P}{U}\right] \qquad (14)$$

and we shall deduce each of these successively from the preceding, starting from

$$\frac{\Pi_0}{P}=\sqrt{1+2\,M\epsilon}.$$

By means of these two formulæ, we shall obtain for a given value of ϵ successive values, more and more approximate to $\frac{P'}{P}$ which I have designated by $\frac{\Pi_0}{P}\frac{\Pi_1}{P}\frac{\Pi_2}{P}\frac{\Pi_3}{P}\ .\ .\ .\ \frac{\Pi_n}{P}$ and we may take one of these values to represent $\frac{P'}{P}$ according to the degree of approximation desired.

Applications.—1. Low-pressure Boilers.—Let there be an iron boiler of a thickness $e=14$ millimètres (0·551 inch), the maximum of the thicknesses in common use. We have $K=374$. Take $K'=23$, the co-efficient of marble, although superior to that of the calcareous crust. Take also $\gamma=23$; and let $\eta=0{\cdot}1$ millimètre (0·00394 inch), we have

$$\frac{\Pi_0}{P}=\sqrt{1+1{\cdot}353\ \epsilon}.$$

If the conditions of draught are good (in which case we practically admit that the air which passes through the grate is one-half consumed, and that the gases of combustion pass into the chimney at a mean temperature of 300° (572° Fahr.), the loss for draught $\frac{P}{U}$, for the not incrusted boiler is 0·25, supposing that the coal burned be of medium quantity.

Formula (14) becomes, in this case,

$$\frac{\Pi_n}{P}=\sqrt{1+1,353\ \epsilon}.\ \left[0,75+\frac{\Pi_{n-1}}{U}\right]$$

making successively $\epsilon=1$, 2, 3, 4, 5 millimètres, (respectively, 0·03937, 0·06874, 0·11811, 0·15748, 0·19685 inches, and determining for each of these thicknesses of separation, the values $\frac{\Pi_0}{P}\ \frac{\Pi_1}{P}\ \frac{\Pi_2}{P}\ .\ .\ .\ \frac{\Pi_5}{P}$, and taking this last as the approximate value to $\frac{P'}{P}$, we form the following table, in which the column entitled $\frac{U'-U}{U}$ gives the increase of consumption due to incrustation, relatively to the actual consumption U′; and, consequently, the economy which would be realized by the absence of any incrustation.

ϵ	$\frac{\Pi_0}{P}$	$\frac{\Pi_1}{P}$	$\frac{\Pi_2}{P}$	$\frac{\Pi_3}{P}$	$\frac{\Pi_4}{P}$	$\frac{\Pi_5}{P}$	Approximate Values of				
							$\frac{P'}{P}$	$\frac{P'}{U}$	$\frac{P'-P}{U}$ Increase of Consumption due to Incrustation	$\frac{U'}{U}$	$\frac{U'-U}{U'}$ Realizable Saving by the absence of Incrustation
mm. 0	1·00	1·00	1·00	1·00	1·00	1·00	1·00	0·250	0·000	1·000	0·000
1	1·53	1·73	1·81	1·84	1·85	1·85	1·85	0·462	0·212	1·212	0·175
2	1·93	2·38	2·59	2·69	2·74	2·77	2·77	0·692	0·442	1·442	0·307
3	2·25	2·95	3·34	3·56	3·69	3·76	3·76	0·940	0·690	1·690	0·414
4	2·53	3·49	4·10	4·49	4·73	4·89	4·89	1·222	0·972	1·972	0·492
5	2·78	4·02	4·88	5·47	5·88	6·17	6·17	1·542	1·292	2·292	0·563

Thus for a thickness of crust $\epsilon=1$ millimètre (0·03937 inch), the realizable economy is at least 17·5 per cent. of the actual consumption: and if the incrustation were of 5 millimètres (0·1968 inch), the realizable saving by getting rid of it would be at least 56·3 per cent.

1st. But the incrustation has not the same thickness over all points of the heating surface, as we have supposed in the calculation. In the boilers of the six steam-ships which I have examined, I have constantly found incrustation of from 1·5 (0·590 inch) to 2 millimètres (0·0787 inch) on the furnace flues, and increasing to 10 (0·3937 inch) and 15 millimètres (0·5905 inch) on the rest of the heating surface. And since these steam-ships, belonging to different companies, were always well kept, we cannot suppose that *their* boilers were in an exceptional state of incrustation, and that those of other ships were not at least as much incrusted: so we may admit, in general, as a minimum thickness of incrustation, 1 millimètre on the direct surface, and gradually increasing to 10 millimètres on the indirect surface, which would give a mean minimum of 5 millimètres. And these thicknesses of incrustation should be

considered as permanent in steam-ships of commerce, because absolute cleanings either are not made at all, or are illusive; the crusts being too adhesive, and their positions too difficult of access.

We may thus take as the average effect of incrustation on naval boilers, that which would be produced by a crust of a uniform thickness of 5 millimètres, which effect would, consequently, be a loss of 56·3 per cent.

Nevertheless, on board transatlantic and government steam-ships, where brine-pumps of continuous action are made use of, and where the great dimensions of the boilers allow of almost perfect cleansing at each voyage, by means of the hammer, the mean effect of incrustation should scarcely pass that which would be due to a uniform thickness of crust of 2 millimètres (0·0787 inch), producing a loss of 30 per cent.

Thus if it be wished to indicate, in a general manner, and without the distinction of high or low-pressure, the loss produced by incrustation in naval boilers, it should be brought to about 40 per cent. of the actual consumption.

In the boilers of land engines fed with fresh water, the incrustation is in general thinner, because the cleanings, which ordinarily take place once a month in well-regulated factories, reach every part of the surface—more accessible in wagon (*à tombeau*) than in flued (*à galeries*) boilers. Notwithstanding, these cleanings are incomplete, and only remove, the thicker mud formations and crusts, so that these boilers remain always in a permanent state of incrustation, the effect of which may be viewed as equal to that produced by an incrustation of uniform thickness of at least 3 millimètres (0·118 inch), which is a loss of 41·4 per cent., say 40 per cent.

2nd. *Boilers of land engines of a medium pressure.*—Suppose a tubular boiler, on the American system, of iron, working at 3 atmospheres. The regular thickness of the outside case will be from 8 (0·315 inch) to 9 millimètres (0·345), that of the tubes, &c., will be less, but I shall suppose a uniform thickness of 8 millimètres, an hypothesis which tends to lower the estimate of the loss.

We have $\frac{\Pi_0}{P}=\sqrt{1+1,8581,\ \epsilon}$, and the general expression (14) becomes

$$\frac{\Pi_n}{P}=\sqrt{1+1,8581.\ \epsilon}\left[0,75+\frac{\Pi_{n-1}}{U}\right].$$

This expression would give us the means of forming a table analogous to the preceding; the following are the more essential results:—

Values of $\epsilon=$	0	1	2	3	4	5
Values of $\frac{U'-U}{U'}=$	0·000	0·229	0·384	0·501	0·594	0·671

3rd. *Of Boilers of land engines, high-pressure* (5 atmospheres).—Suppose an iron cylindrical boiler of one mètre diameter (39·370 inches), working and registered (*timbrée*) at 5 atmospheres. The regulated thickness of the body of the boiler is 10 millimètres (0·3937 inch). Suppose the tubes to have the

same thickness, although in general this is less, and take the other data as in the preceding applications, we have

$$\frac{\Pi_o}{P}=\sqrt{1+1,3707.\ \epsilon} \text{ and } \frac{\Pi_n}{P}=\sqrt{1+1,3707,\ \epsilon}\left[0,75+\frac{\Pi_{n-1}}{U}\right]$$

whence we deduce

Values of $\epsilon=$	0	1	2	3	4	5
Values of $\frac{U'-U}{U'}=$	0·000	0·178	0·306	0·409	0·499	0·568.

Here again the incrustation may be reduced, as far as the mean effect is concerned, to that arising from a crust of a uniform thickness of 3 millimètres (0·118 inch); the loss will be 40·9 per cent., say 40 per cent.

4th. *Locomotive boilers.*—In these boilers the mean temperature of the heating surface, designated by A, is higher than in other boilers. On the other hand the gases of combustion having a small distance to travel to arrive at the chimney, and being there rapidly carried off by a strong draught, remain but a short time in contact with the heating surface. They must escape into the atmosphere at a temperature above 300° (572° Fahr.) Let us find the approximate value of this temperature. We have said that in the furnace of a fixed engine the gases of combustion enter the chimney at 300°, and that then the loss of fuel is 0·25, when coal of ordinary quality is employed. In a locomotive, burning coke, this loss is still greater, for 1 kilogramme (2·205 lbs.) of coke, representing 6000 units of heat, only evaporates 6 kilogrammes (13·289 lbs.) of water at 10° (50° Fahr.) of initial temperature, and consequently only utilises 3840 units: the loss is then

$$\frac{6000-3840}{6000}=0{\cdot}36.$$

If coke and coal produced in their combustion the same quantity and the same kind of gas, it is evident that the mean temperatures of these gases, T_k for coke and T_h for coal, would be proportional to the losses 0·36 and 0·25 and we would have $\frac{T_k}{T_h}=\frac{0{\cdot}36}{0{\cdot}25}=1{\cdot}44$.

But coal requires more air than coke; besides, it produces watery vapour, while coke produces none, and this vapour sensibly diminishes the heat by taking it up as latent, to a greater extent than in the gaseous products of coke; whence it follows that we have in reality $\frac{T_k}{T_h}>1{\cdot}44$.

If then we suppose $\frac{T}{T_h}=1{\cdot}44$ or $T_k=432°$ (809·6° Fahr.), and that we take it to express the mean temperature A, of the exterior of the heating surface, we make an hypothesis which diminishes the value of $\frac{\Pi_o}{P}$. Let us then make A=430° (806° Fahr.) Let the boiler be one working at 5 atmospheres. The temperature of the water will be $b=153°$. The boiler being of copper or brass,

we have $K=900$. Always making $K'=\gamma=23$ and $\eta=0{\cdot}1$ millimètre (0·0039 inch). The thickness e varies much according to the points of the heating surface; it is 24 millimètres (0·945 inch) for the fire-box, and 2 millimètres (0·079 inch) for the tubes: we shall take the mean of these thicknesses for e, taking into account the ratio of the surfaces of the fire-box and of the tubes: these surfaces are in the ratio of 1 for the fire-box to 10 for the tubes, we shall therefore take

$$e=24\times\tfrac{1}{10}+2\times\tfrac{9}{10}=4{\cdot}2\text{; let } e=5 \text{ millimètres (0·197 inch).}$$

The general expression (14) here becomes

$$\frac{\Pi_n}{P}=\sqrt{1+4{\cdot}3025.\,\epsilon}\left[1+\frac{\Pi_{n-1}}{U}-\frac{P}{U}\right],$$

in which we must make

$$\frac{P}{U}=0{\cdot}36\,;$$

which gives

$$\frac{\Pi_n}{P}=\sqrt{1+4{\cdot}3025.\,\epsilon}\left[0{\cdot}64+\frac{\Pi_{n-1}}{U}\right].$$

As to the values of ϵ which should be considered; it is to be remarked, that on account of the high temperature of the furnace, of the small thickness of the metal of the tubes, and of the frequent variations in the intensity of the fire, occasioned by the variations in the work itself, according to the gradients (*les pentes à gravir*) the dilatations and contractions of the metal of these boilers are great and frequent; these movements of the metal detach the incrustations, and we may admit, in general, that these do not exceed the thickness of 1 millimètre, and that while at work the surface is always incrusted in some places and not in others. We shall form then the values $\frac{\Pi_0}{P}\,\frac{\Pi_1}{P}\ldots\frac{\Pi_4}{P}\,\frac{\Pi_5}{P}$ for the values of ϵ increasing by $\frac{1}{10}$ from 0·1 to 1 millimètre; and we shall take the mean of the corresponding values of $\frac{U'-U}{U'}$ to express the *mean effect of the incrustation.*

Making the calculations the following values are found:—

Values of ϵ =	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0
Values of $\frac{U'-U}{U'}$ =	0·103	0·194	0·280	0·353	0·384	0·475	0·524	0·571	0·611	0·647

The mean of these ten values of $\frac{U'-U}{U'}$ is 0·414.

Thus the loss of fuel due to incrustation in a locomotive boiler, may be estimated in the mean as, at least, 40 per cent. of the actual consumption.

NOTE No. 2.

FORMATION OF DEPOSITS IN NAVAL BOILERS.

On evaporating some water of the ocean or Mediterranean, by ebullition, in a glass flask, at the pressure of the atmosphere, I have observed the following facts :—

1. From the commencement of the ebullition there is a disengagement of carbonic acid.

2. The liquid remains limpid for some time: but when it is reduced to about $\frac{1}{3}$ of its volume it becomes opalescent, and very minute flakes of magnesia are perceived.

3. When the volume of the liquid is reduced to about $\frac{1}{3}$, carbonic acid is detected in the floculent precipitate. It exists there, combined with magnesia only, and in the state of sesquibasic carbonate: no carbonate of lime is present.

4. When the liquid is reduced to about $\frac{1}{4}$ of its volume and indicates from 12° to 13° of the aërometer of Beaumé, a white crystalline deposit is formed, adhering to the sides of the flask. This deposit is sulphate of lime, mixed with a small quantity of subcarbonate of magnesia, of free magnesia, and sometimes with a little perchloride of magnesium.

5. By continuing the ebullition the white crust is developed.

6. During the whole time of ebullition, even when it has been pushed so far that the sea salt deposits itself, there is a disengagement of carbonic acid; and it is remarkable that the liquid, formerly limpid, then opaline, then milky, gradually clears and tends to resume its original limpidity.

7. All these facts are explained by the following considerations, derived from the composition of sea-water, and regard being had to the laws of chemical stability.

We know that this composition, almost uniform for the open ocean and the Mediterranean, and probably, also, for the other regions of the sea, at least as far as regards the nature of the salts dissolved, consists qualitatively of

Chlorides of sodium, magnesium, potassium, and calcium.
Sulphates of magnesia and lime.
Carbonates of magnesia and lime.
Alkaline bromides and iodides.
Traces of metals, &c.

We know, besides, that the magnesian salts, of each acid, have a greater proportion in this compound than the corresponding calcareous salts.

If, then, we boil such a saline solution, the following are the results :—

1. At the first ebullition the disengagement of the air and carbonic acid simply dissolved; then the disengagement of that part of this acid which holds the carbonate of lime in solution, and a tendency of this salt to precipitate.

2. But in presence of chloride of magnesium which, by ebullition, tends to quit its acid, the carbonate of lime will pass into the state of chloride of calcium, free magnesia will be formed, and carbonic acid disengaged. This reaction may be very neatly verified, *a posteriori;* when even a very weak solution of chloride of magnesium is boiled with pounded chalk, carbonic acid is disengaged in abundance, and magnesia is perceived in the liquid in a floculent opalescent state.

3. The neutral carbonate of magnesia, although more stable, in salt than in pure water, has nevertheless, a tendency to quit its acid and to deposit itself in the state of sesquibasic carbonate; and this decomposition, which does not take place from the commencement of the ebullition, will, nevertheless begin, when the boiling point shall have been sufficiently raised by concentration. From that time the disengagement of carbonic acid, begun by the decomposition of the carbonate of lime, continues in virtue of that of the carbonate of magnesia.

4. The subcarbonate of magnesia thus formed, reacts in its turn on the chloride of magnesium, by yielding magnesia to it to form oxychloride, and itself passing into the state of neutral carbonate to be decomposed anew, and directly into carbonic acid and a less quantity of subcarbonate. This reaction may be easily verified. If we boil a solution of chloride of magnesium, to which is added subcarbonate of magnesia, carbonic acid is evolved in large quantity. It is conceivable that the action takes place between four equivalents of chloride of magnesium, and four equivalents of subcarbonate; there will be produced four equivalents of oxychloride of magnesium, three equivalents of carbonic acid, and three equivalents of subcarbonate.

$$\text{Thus } \left.\begin{matrix} 4(Cl.\ Mg) \\ 4[(CO^2)^3+(Mg\ O)^4] \end{matrix}\right\} = \left\{\begin{matrix} 4[(Cl.\ Mg)+Mg\ O] \\ 12(CO^2+Mg\ O) \end{matrix}\right\} = \left\{\begin{matrix} 3(CO^2) \\ 3[(CO^2)^3+(Mg\ O)^4]. \end{matrix}\right.$$

This reaction will continue until the subcarbonate be exhausted, the chloride of magnesium being in sufficient quantity for this. The free magnesia also will participate in this reaction, and be absorbed by the chloride of magnesium, and possibly, also, by the sulphate of magnesia. So that the liquid will have a tendency to lose its milky aspect, which was due to the magnesia and to the subcarbonate.

5. Once the carbonate of lime is transformed into chloride, the lime will only exist in the state of a soluble salt, as chloride and sulphate. But, since the first of these salts is more soluble than the second, and since it is present with sulphate of magnesia, more soluble also than the calcareous sulphate, it results, that when the water shall have arrived at the point of saturation, as regards the sulphate of lime, there will be a precipitate, not only of the preexisting sulphate of lime, but also of that which the reaction between the chloride of calcium and the sulphate of magnesia produces.

Thus, in the act of incrustation the calcareous salts are all reduced to sulphate, and, we may, as far as regards the incrustation produced by sea-

water, consider all the lime pre-existing in this water as in the state of sulphate.

It results also from what precedes, that the carbonate of lime, although pre-existing in the sea-water, cannot be found in the deposits which it forms in boilers.

FORMATION OF DEPOSITS IN BOILERS FED WITH FRESH WATER.

1. Fresh-waters have a very variable composition according to the districts they pass through. They all contain bicarbonate of lime; most contain also, sulphate of lime in more or less considerable proportion; and these two bodies generally form the principal part of the salts held in solution; for the chlorides of sodium, potassium, calcium, magnesium, and the sulphates of magnesia and potash, which they also generally contain, only exist in very minute proportions.

In incrustation produced by fresh water, the same reactions take place which we have described above, between the calcareous and magnesian salts; but since the latter bear a very small proportion to the former, these reactions have no sensible influence on the result, and we may consider the incrustation as due entirely to the bicarbonate and the sulphate of lime.

2. From the first moment of ebullition, the bicarbonate of lime disengages carbonic acid, and precipitates, in the state of neutral carbonate, in a very fine and light powder, which becomes heavier, and aggregated on prolonged ebullition. This precipitate being very fine, may partly lodge in the roughnesses which the surface of an iron vessel present, but will not accumulate there at all by crystallizing, and consequently will not form any crust. But the carbonate of lime is not perfectly insoluble in water: the quantity which is retained in solution is, according to Buchloz, from $\frac{1}{24000}$ to $\frac{1}{18000}$. It is this part of the carbonate of lime which, as a result of evaporation, gently deposits, by crystallizing, and forms incrustations. Thus in boilers, where the evaporation is very gentle and quiet, and where the water is fed to them through gradually heated conduits, the carbonate produced by the disengagement of carbonic acid, crystallizes, in part, in these conduits and in the calm places above the heating surface, and there forms abundant concretions.

As to the sulphate of lime, it deposits by crystallizing and forming crusts, from the moment when, by concentration, the water has become saturated with this salt. If the ebullition be tumultuous, a part of this salt deposits in small separate crystals.

The crystallization of the calcareous carbonate and sulphate takes place simultaneously, beginning at the moment of saturation of the latter, and these two salts concur in forming the incrustation, the first in a constant proportion (since fresh water in ebullition may be always considered as at the point of saturation with neutral carbonate), and the second in a variable proportion according to the richness of the water in sulphate.

NOTE No. 3.

SOLUBILITY OF SULPHATE, AND CARBONATE OF LIME IN WATER BOILING UNDER DIFFERENT PRESSURES.

In general, salts are more soluble hot than cold within certain limits of temperature. Certain calcareous salts, or at least the sulphate and carbonate, are among the exceptions to this rule. I have observed, in fact, with regard to the sulphate, that when, by ebullition under the pressure of the atmosphere, either with spring or sea-water, the commencement of the precipitate of sulphate of lime shall have been determined, the latter redissolves almost entirely on cooling. But since the incrustation is the effect of the crystallization of the sulphate and carbonate of lime, it is essential to study the modifications which the solubility of these salts experiences in water boiling under different pressures, that is to say, at different temperatures.

I.—SOLUBILITY OF SULPHATE OF LIME IN SEA-WATER.

1. I have commenced by determining the proportions of sulphate of lime in sea-water, at different degrees of concentration, produced by ebullition at the pressure of the atmosphere; for degrees above the natural density, and by the addition of distilled water; for degrees inferior to it. In accordance with the remark contained in Note 2, I consider all the lime as existing in the state of sulphate, in sea-water. Table A, following, shows these proportions according to the degrees of Beaumé from 0° to 12°·5—the point of saturation for boiling under the atmospheric pressure, and applies equally to the water of the open sea, and to that of the Mediterranean taken on our coasts. The aërometer of Beaumé was observed at 15° (41° Fahr.) of temperature.

TABLE A.

Concentration in Degrees of Beaumé	Proportions of Sulphate of Lime to 100 of Water	Concentration in Degrees of Beaumé	Proportions of Sulphate of Lime to 100 of Water
degrees		degrees	
0	0·000	7	0·267
1	0·023	8	0·310
2	0·060	9	0·355
3	0·097	10	0·395
4	0·140	11	0·432
5	0·183	12	0·477
6	0·226	12·5	0·500

2. I next determined the degree of temperature at which water boils, when concentrated to 12°·5 of the aërometer, under the atmospheric pressure. I found 103° (217°·4 Fahr.) was the boiling point.

Then, for the different temperatures comprised between 103° and 130° (217° and 267° Fahr.) I have determined the degree of concentration at which water arrives when saturated with sulphate of lime, and the above table A gives me the corresponding solubility. For this end I took samples of water brought to

various degrees of concentration. I introduced a small quantity of each of them into tubes of 0·1 decimètre (3·930 inches) long, 0·01 centimètre (0·390 inch) in diameter, and 0·001 millimètre (0·039 inch) thick, drawn out at one end and then closed in the spirit lamp. I placed in a bath of oil, heated to the proper temperature, five or six of these tubes, marking consecutive degrees of concentration. After about an hour and a half of heating, I noted such of these tubes as contained a deposit of sulphate of lime. The degree of concentration at which saturation takes place for this temperature being comprised between that of the tubes containing a deposit, which marked the lowest degree, and that of the tubes containing no deposit, which marked the highest degree, I recommenced the operation with a water of an intermediate degree. And I thus succeeded in determining the degree of concentration which the liquid possesses when saturated, and at the temperature of the experiment; I thus found

Temperatures Cent. - - - -	103°	111°	119°	125°	130°
Do. Fahr. - - -	217°·4	231°·8	246°·2	257°	267°
Degrees of concentration at which saturation takes place, - -	12°·5	9°	5°·8	3°·75	2°

These results admit of the construction of a curve which graphically represents the relation existing between the temperatures, reckoned from 103° as origin, and considered as abscissæ; and the degrees of concentration considered as ordinates, reckoned from 0.

The curve is very nearly a right line; which proves that since the pressures increase rapidly with the temperatures, the solubility of the sulphate decreases rapidly in proportion as the pressure increases.

By combining the results given by this curve with those in Table A—the solubility corresponding to different temperatures is known. Thus we have constructed the following table:—

TABLE B.

Solubility of Sulphate of Lime in Sea-water at different Temperatures.

Degrees of the Aerometer corresponding to the Saturation	Temperatures Cent.	Temperatures Fahr.	Solubility of the Sulphate of Lime to 100	Degrees of the Aerometer corresponding to the Saturation	Temperatures Cent.	Temperatures Fahr.	Solubility of the Sulphate of Lime to 100
	deg.	deg.			deg.	deg.	
12·5	103·00	217·4	0·500	6	118·50	245·30	0·226
12	103·80	218·84	0·477	5	121·20	250·16	0·183
11	105·15	221·27	0·432	4	124·00	255·20	0·140
10	108·60	227·48	0·395	3	127·90	262·22	0·097
9	111·00	231·80	0·355	2	130·00	266·00	0·060
8	113·20	235·76	0·310	1	133·30	271·94	0·023
7	115·80	240·44	0·267				

3. We see that from 130° (166° Fahr.) degrees of temperature, the solubility of sulphate of lime becomes very slight. It is important for the question before us to be convinced whether this solubility becomes nil at any temperature, and, if so, to determine this, or at least a limit superior to it. To make this point clear, I took 100 cubic centimètres (0·610 cubic inches) of distilled water, to which I added two drops of natural sea-water at 4°·25; each drop forming 0·068 of a cubic centimètres, and the two drops, containing, consequently, $2 \times 0{\cdot}068 \times 0{\cdot}0015 = 0^{gr}{\cdot}0002$ of sulphate of lime. The mixture contained then 0·000002 of this salt. I then exposed to a temperature of 140° (284° Fahr.) a closed glass tube containing a little of this water. In about fifteen minutes I examined the tube, by placing it between the eye and the sun's rays, and I constantly had a deposit in the form of indefinitely fine iridescent pellicles, swimming in the liquid. These pellicles are nothing but sulphate of lime deposited on the side, and afterwards detached by the contractions of the glass from contact with the cold air.

I then performed a similar operation with 100 cubic cent. of distilled water and two drops of another mixture, containing $\frac{1}{40}$ of sea-water. The whole mixture, consequently, contained a proportion of sulphate of lime expressed by

$$\frac{0{\cdot}068 \times \frac{2}{40} \times 0{\cdot}0015}{100} = 0{\cdot}00000005.$$

In about thirty minutes I recognised the presence of small pellicules, as in the preceding experiment.

We may then consider sulphate of lime as totally insoluble in sea-water, and *a fortiori* in fresh water, at temperatures between 140° and 150° (284° and 322° Fahr.); and this fact will be additionally confirmed hereafter.

It is worthy of remark that the deposits of sulphate obtained in these experiments, dissolve on cooling again, but at a rate decreasing as the temperature at which they are formed increases. Thus the precipitate obtained at 150° (322° Fahr.) takes five or six days to redissolve completely.*

II.—SOLUBILITY OF SULPHATE OF LIME IN FRESH WATER.

What we have said of the solubility of sulphate of lime in sea-water, at temperatures above 130° (266° Fahr.), evidently applies also to fresh water; and this suffices for the solution of the present question.

III.—SOLUBILITY OF CARBONATE OF LIME IN FRESH WATER.

The solubility of carbonate of lime, greatly inferior to that of sulphate for temperatures, but a little above 100° (212° Fahr.), decreases less quickly than the

* It appears allowable to conclude from these facts that the insolubility of sulphate of lime at an elevated temperature, is the effect of the complete dehydration of this salt; and this circumstance would lead to a very plausible explanation of the geological formation of the mineral Anhydrite.

former in proportion as the temperature increases, and it happens at a point when the sulphate of lime becomes less soluble than the carbonate. In fact, if we put into a glass tube, which we afterwards close by a spirit lamp, some carbonate of lime recently precipitated, and a solution of sulphate of ammonia, soda, potash, or magnesia, and heat it gradually to 130° or 140° (234° or 284° Fahr.), crystals of sulphate of lime are formed which line the sides of the tube, and the water becomes alkaline.

As in the case of sulphate of lime, the carbonate always becomes less and less soluble in proportion as the temperature rises; and at 150° (322° Fahr.) we may consider this solubility as *nil*. In fact, if we expose to this temperature for some time, water holding the neutral carbonate in solution, it forms a cloudy precipitate; and, if immediately after the cooling of the liquid it be filtered, and oxalate of ammonia be poured into it, we do not perceive any muddiness in it, even after the lapse of several days, which proves that the carbonate of lime has become at least as insoluble as the calcareous oxalate.

This fact, joined to that which we have just mentioned of the reaction between carbonate of lime and alkaline sulphates, confirms the total insolubility of sulphate of lime, as we have directly proved above.

This fact also proves another important point, namely, that not only is the carbonate of lime entirely precipitated by a temperature of 150° (322° Fahr.), but also, that this precipitate either remains insoluble in the water when cooled again (protected by the carbonic acid), or only redissolves very slowly.

NOTE No. 4.

TRIALS OF THE PROCESS OF EVACUATION.

To ascertain the degree of efficacy of which the process of evacuation is susceptible, as a preservative against incrustation in low-pressure boilers, I have submitted it to the following tests :—(Fig. 14, Pl. VI.)

A cylindrical iron boiler A, holding about (50 litres) 11 gallons, was erected upon a furnace almost under the same conditions as the boiler of a fixed engine; it presented a "direct" heating surface (or directly exposed to the rays of the fire and the contact of the flame) for half its length, and an "indirect" heating surface (or exposed only to the contact of the gases of combustion) for the other half of its length. The burnt gases and the smoke entered the flue C, wound round the back of the boiler and returned over the sides by the flue C′, whence they passed into the chimney B.

The fire, made of *Mons* coal, was trimmed (*poussé*) almost as in an ordinary steam-engine, and the waste cock R was opened so that the pressure should not exceed that of $\frac{1}{2}$ mètre of water, or $\frac{1}{20}$ of an atmosphere.

Sea-water was evaporated of density of 3°·5 of Beaumé. The feeding-water was introduced by a pump, worked by a man, as it was wanted. The evacuation was performed by another pump; the motion of which, connected with that of the feed-pump, was regulated by an intermittent apparatus ("*temps perdu,*") so as to obtain an evacuation, having the desired proportion to the supply.

Although nearly convinced that this arrangement would not give a sufficiently regular and precise evacuation, I yet wished to attempt it, so as to know with certainty what to hold to in the working of brine-pumps for sea-water, employed on board the transatlantic steamers and those of the French Fleet. Experience has fully confirmed these expectations: although the feeding-water was limpid, and the boiler also had been cleaned as well as possible, the water was soon clouded with a brown precipitate of oxide of iron and of magnesia, which obstructed the valve every instant, and hindered it from falling exactly into its seat; the draught of the pump became irregular, and sometimes it did not act at all. I was then obliged to give up the employment of the pump, and the evacuation was performed by means of a cock, worked by hand, at intermittent intervals of about six minutes. Each evacuation was followed immediately by a supply in the desired proportion, and each time the density of the evacuated water was noted, to make sure that the degree of concentration which was proposed as a limit, was not exceeded.

1*st Experiment.*—In this experiment the water evacuated was constantly $\frac{1}{3}$ of the feed; and since its object was to maintain the density below 11° of Beaumé, it only commenced when the water was at 9°. The operation lasted for five days, for five hours at a time. We evaporated in all 200 litres=44·02 gallons—say at the rate of (8 litres) 1·626 gallons per hour; and since the heating surface was (0·31 square mètre) 3·336 feet, the evaporation was (25 litres) 5·503 gallons per (1·00 square mètre), 10·76 square feet, at the ordinary rate of evaporation in boilers. The result of this experiment was a perceptible incrustation on the direct heating surface: the crust (1·5 millimètres) 0·059 inch, at the thickest place; it covered the bottom of the boiler to the extent of the arc *ab*, a little longer in the horizontal direction than the breadth of the grate; it was bounded by two lines almost coincident with the tubes (*génératrices*), passing through the points *a* and *b*; only towards the end of flue C, the crust rose towards the tube (*génératrice*) *a'*, thus following, so to speak, the movements of the flame. The other parts of the indirect surface were without incrustation and perfectly clean.

2*nd Experiment.*—Another experiment was made under the above conditions, with this sole difference, that the evacuation was $\frac{1}{2}$ instead of $\frac{1}{3}$ of the feed. Thus, during the whole operation, the water was kept below 8° of concentration. There were evaporated (200 litres) 44·02 gallons in the space of 25 hours, and almost the same rate of evaporation as before—of (8 litres) 1·626 gallons per hour. The result was almost the same as in the former experiment.

We must conclude from these results that the process of evacuation is but

imperfectly efficacious: it prevents incrustation on the indirect heating surface, but it is powerless to protect the direct heating surface.

NOTE No. 5.

LOSS OF MOTIVE FORCE CONSEQUENT ON THE RESISTANCE OF THE CONDENSER.

Let us consider a condenser of any system whatsoever, in which the destruction of the steam is not instantaneous, and experiences a certain delay, corresponding to a fraction of the stroke of the piston. Thus, L being the length of the stroke, n L may express the delay which the complete destruction of the steam experiences at each single stroke of the piston, or the part of the stroke during which the condensation is taking place. And to pass from this general case to that of the ordinary condenser, where the condensation is very nearly instantaneous, it will be only necessary to make $n=o$ in the formulæ.

Let T_u be the utilised part of the work of the engine.

T_r The resisting work of the condenser—on any system whatsoever.*

Π The pressure of the steam before the cut off.

P The pressure of the steam at the end of the cut off, or at the end of the stroke of the piston, or at the moment when the steam, which is then in the cylinder, begins its condensation.

p The normal pressure in the condenser, namely, that which exists after condensation, and due solely to the temperature of the condensed water.

L The length of the stroke of the piston.

E The part of this stroke which is made under the pressure Π before cutting off.

n L The fraction of the stroke during which the condensation is progressive and after which the condenser takes the normal pressure, p.

m The ratio obtained by dividing the sum of the capacities of the cylinder and of the void part of the condenser, by the capacity of the cylinder—that is to say,

$$\frac{\text{Cylinder}+\text{Condenser}}{\text{Cylinder}}=m$$

Whence the initial pressure of the steam, at the moment when it enters the condenser, will be in the inverse ratio of the volumes $\frac{P}{m}$ neglecting the pressure p in relation to P.

During the period n L of the stroke, the pressure in the condenser diminishes gradually from $\frac{P}{m}$ to p; and during the period $(1-n)\cdot L$, the pressure remains constant and equal to p. Referring to figure 15, plate VI., if we represent L by aa'',

* We only consider here the resistance due to pressure, and ignore the existence of friction in the air-pump.

nL by aa', then $(1-n)$L will be represented by $a'a''$. And if we take the ordinate a A $= \frac{P}{m}$, and the ordinates a'B, a''C equal to p; the successive pressures through which the condenser passes, will be represented by the ordinates of a certain line, which will be right from B to C, and curved from B to A, but which will be tangent in B, to the part B C.

The work T_r of the condenser will be expressed by the surface S of the piston, multiplied by the area of the curve A B C; for this area expresses the sum of the elementary products of the pressure, for the elementary space passed through.

The area a' B C a'' is equal to $(1-n)$ Lp. To determine the area a A B a' we must know the curve A B. For a particular case we may determine it, experimentally, by Watt's indicator; but, in this general analysis, we shall replace this curve by a parabola, having its vertex in B, passing at the point A, and whose axis will, consequently, be parallel to the axis of Y. This will differ generally but little from the true curve.

This parabola will be of the form: $y=ax^2+\tau x+\gamma$, and to determine the co-efficients, we shall have the following equations:

$$y_o=\gamma$$

$$\gamma aa'=an^2L^2+\tau nL+\gamma=p$$

$$\frac{d\gamma aa'}{dx}=2\,an\,L+\tau=o.$$

whence we derive

$$a=\frac{\frac{P}{m}-p}{n^2\,L^2},\quad \tau=-2\,\frac{\frac{P}{m}-p}{nL},\quad \gamma=\frac{P}{m}$$

and the equation of the curve becomes

$$y=\frac{\frac{P}{m}-p}{n^2L^2},\quad x^2-2\,\frac{\frac{P}{m}-p}{n\,L}\quad x+\frac{P}{m},$$

and for the area a A B a' we shall have

$$\int_o^{n\,L} y\,dx=\frac{n}{3}L\left(\frac{P}{m}+2\,p.\right)$$

We then have for the resisting work of the condenser:—

$$T_r=SL\left[\frac{n}{3}\left(\frac{P}{m}+2p\right)+(1-n)p\right]=SL\tfrac{1}{3}\left[n\,\left(\frac{P}{m}-p\right)+3p\right].$$

The work developed by the motor T_m is:—

$$T_m=S\Pi E\left[1+2{\cdot}3026.\ \log\frac{L}{E}\right];$$

and we know that the useful work T is generally 0·6 of T_m. We then have

$$T_u=S\Pi E.\ 0{\cdot}6\left[1+2{\cdot}3026.\ \log\frac{L}{E}\right].$$

Comparing now the resisting work of the condenser with the useful work, we have

$$\frac{T_r}{T_u}=\frac{5}{9}\,\frac{L}{E}\,\frac{n\left(\frac{P}{m}-p\right)+3p}{\Pi\left(1+2\cdot3026.\ \log\frac{L}{E}\right)}. \tag{1}$$

Such is the relation which exists between the resisting work of any condenser whatsoever, and the useful work.

Making $n=o$ for the case of the ordinary condenser, and designating this particular value of T_r by T_r^o we have

$$\frac{T_r^o}{T_u}=\frac{5}{3}\,\frac{L}{E}\,\frac{p}{\Pi\left(1+2\cdot3026.\ \log\frac{L}{E}\right)} \tag{2}$$

and dividing member by member (1) by (2), we have

$$\frac{T_r}{T^o}=1+\frac{\frac{P}{m}-p.}{3p}.n. \tag{3}$$

and consequently

$$\frac{T_r-T^r}{T_r^o}=\frac{\frac{P}{m}-p}{3p}.n. \tag{4}$$

This last formula expresses the increase of resistance due to the delay which the condensation experiences, a delay expressed by the fraction n. And as the co-efficient.

$$\frac{\frac{P}{m}-p}{3p}$$

is greater than unity in all its applications, this increase of resistance will be considerable, unless n be a small fraction.

APPLICATIONS.

1. *Low-pressure engines* (1·25 atmospheres). $\Pi=950$ millimètres (37·381 inches) mercury; supposing the steam cut off at $\frac{2}{3}$, $P=634$ millimètres (24·960 inches); supposing condensation [illegible] (66° Fahr.), of temperature, $p=31$ millimètres (1·220 inches), and let $m=2$, the greater m is, the less is the resistance, due to the delay of the condensation. But the dimensions of the condenser cannot be greatly enlarged, especially in [illegible] marine engine. We shall suppose, as the most favourable case, that the vacuum chamber of the condenser has a capacity equal to that of the cylinder, when $m=2$.

We have:

$$\frac{T_r-T_r^o}{T_r^o}=3\cdot07.\ n;\ T_r^o=0\cdot058.\ T_u;\ \text{and for } n=1,\ T_r=0\cdot236.\ T_u.$$

2. *Medium-pressure engines* (3 atmospheres). $\Pi=2280$ millimètres (89·764 inches), steam cut off at $\frac{1}{8}$; $P=456$ millimètres (17·953 inches); $p=31$ millimètres (1·220 inches).

We have

$$\frac{T_r-T_r^o}{T_r^o}=2{\cdot}12.\ n\ ;\ T_r^o=0{\cdot}043.\ T_u\ ;\ \text{and for } n=1,\ T_r=0{\cdot}134.\ T_u.$$

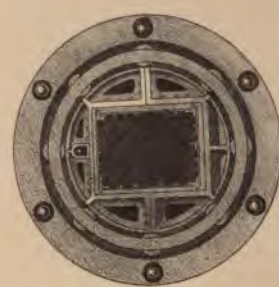
3. *High-pressure engines* (5 atmospheres). $\Pi=3{,}800$ millimètres (159·606 inches), steam cut off at $\frac{1}{10}$, $P=380$ millimètres (15·961 inches); $p=31$ millimètres (1·220 inches),

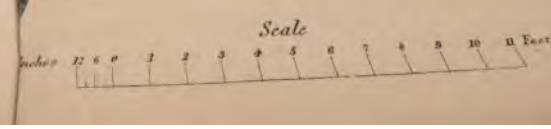
We have

$$\frac{T_r-T_r^o}{T_r^o}=1{\cdot}71.\ n\ ;\ T_r^o=0{\cdot}041.\ T_u\ ;\ \text{and for } n=1,\ T_r=0{\cdot}111.\ T_u.$$

It appears from this how important it is that n be a small fraction; that is to say, that the time of condensation of the steam, be very short compared with that of a single stroke of the piston.

ATE, I.





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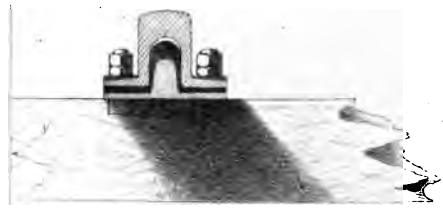
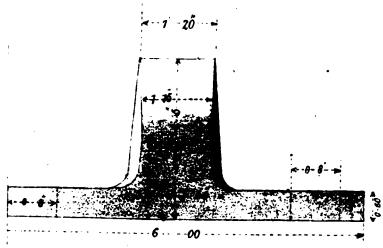


Fig 2



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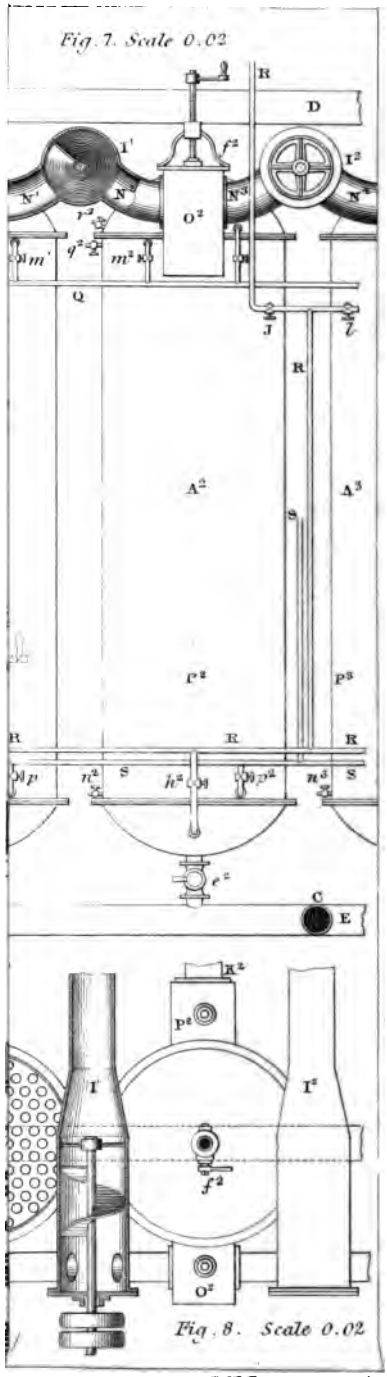
The lines in Red and Blue represent the Conduits, Tunnel and Pipes &c. in Mr. Hassard's scheme for conveying water from the Vartry valley to Dublin.

The Black lines shew the Tunnel & Pipes &c. as adopted by Mr. Hawksley.

The position of the Reservoirs in the Vartry valley being identical or almost so in both cases.

Richd Hassard

Plate 6.



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